Biology

Utah Science Standards

2018-2019

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Science Standards

Utah State Board of Education OER
2018-2019

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Using this Book

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We especially wish to thank the amazing Utah science teachers whose collaborative efforts made the book possible. Thank you for your commitment to science education and Utah students!

cK-12

Students as Scientists

Many students equate science to learning vocabulary terms, labeling pictures, and memorizing facts. Science by nature is much more inclusive and loosely defined. Have you ever asked yourself questions about your surroundings and wondered how or why they are happening? This is science. Science works best when driven by curiosity and innovation. In order for you to experience science in its fullest sense you must take it beyond the textbook and into your everyday experience, but in order to be meaningful there are certain guidelines that can help us. Science is not constrained to Biology, but there are cross-cutting concepts threaded throughout all scientific disciplines. These include:

- **Patterns:** (All life uses the same genetic code DNA. The nucleus of plant cells have chromosomes that contain DNA. The nucleus of human cells have chromosomes that contain DNA. Bacteria cells contain DNA.)
- **Cause and effect:** Mechanism and explanation; (Coyotes hunt grazing cattle and decrease the cattle population, so the Division of Wildlife pays a bounty for coyote ears. The population of coyotes becomes endangered, so the Division of Wildlife puts a ban on killing coyotes. Cattle farmers notice that their cattle herds start decreasing, so they ask for the Division of Wildlife to offer a bounty on coyotes.)
- **Scale, proportion, and quantity:** (The maximum nonlethal dose of Tylenol a human can consume a day is 4 grams. When I go to the office and get Tylenol for a headache they give me 200 milligram tablets. How many tablets can I take in one day)
- **Systems and system models:** (The human digestive system has teeth that grind up food so that it can be absorbed and the excess food gets excreted. The bird digestive system has a gizzard that grinds up food so that it can be absorbed and the excess food gets excreted. The worm digestive system has a gizzard that grinds up food so that it can be absorbed and the excess food gets excreted.)
- **Energy and matter:** Flows, cycles, and conservation; (The circle of life recycles energy, where the lion eats the antelope. The antelope eats grass. The grass uses the nutrients from the dead lion to grow.)
- **Structure and function:** (Xylem is a hallow tube. In plants xylem is used to transport water from the roots of plants to all ends of the plant.)
- **Stability and change:** (Bacteria will reproduce using mitosis every 20 minutes. Once the bacteria run out of a food source, bacteria will begin dying, while other bacteria continue to reproduce. This leads to a balance of the maximum number of bacteria that the environment will support.)

When studying any specific scientific discipline you should attempt to keep these cross-cutting concepts in mind in order to gain a better perspective of the world as whole and the nature of science. Included in the concepts are the skills and practices that a scientist utilizes. When asking questions about the natural world there are certain skills and practices that can help you be generate better conclusions, explanations and inferences. These practices include:

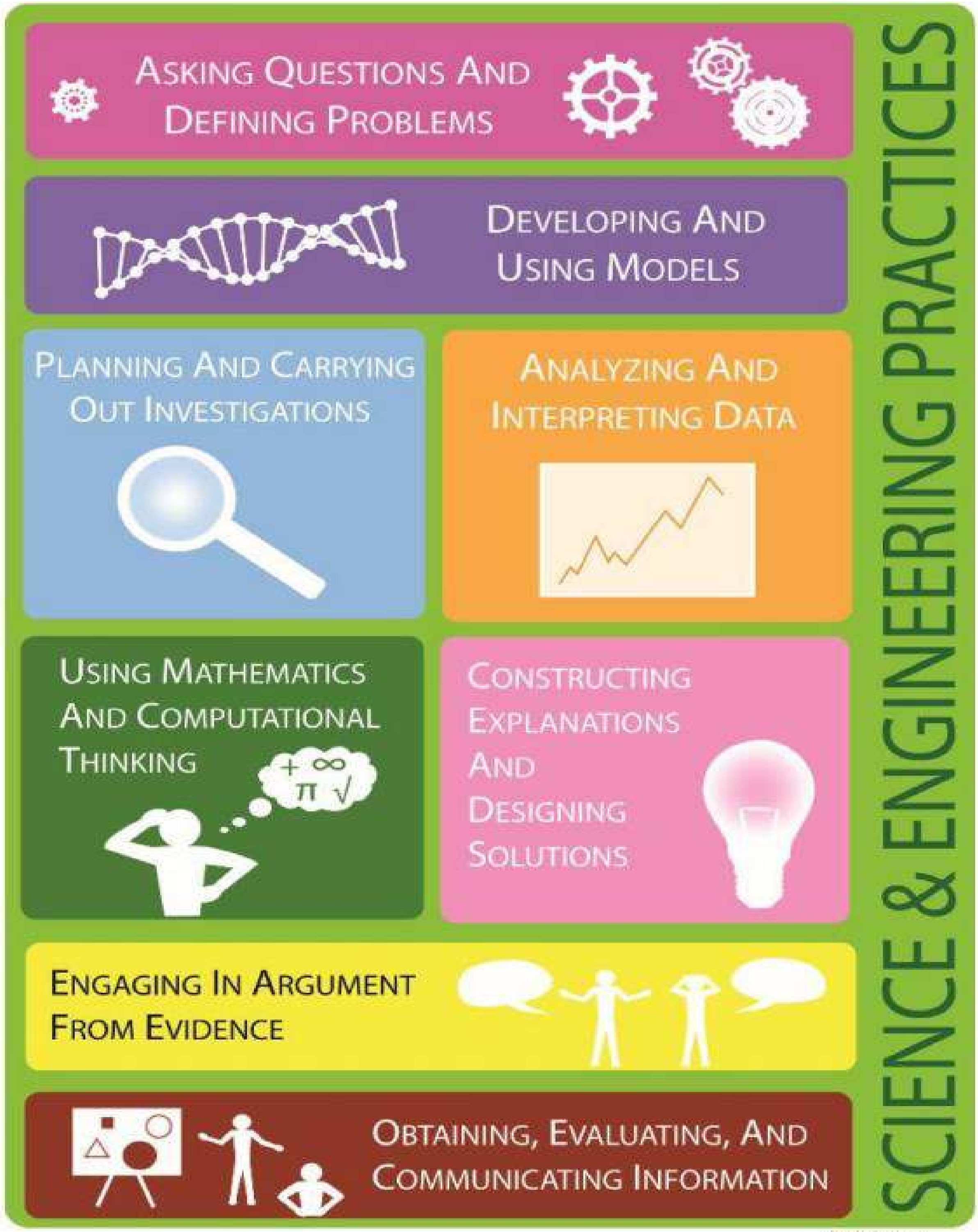
- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Using mathematics and computational thinking
- Constructing explanations and designing solutions
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

While these practices and cross-cutting concepts are crucial to your overall success in science, in order to be most meaningful they do need some context. This is where the study of disciplinary core ideas are most impactful. If you study Biology or any other scientific discipline without the cross-cutting concepts and scientific practices then you limit yourself to fact memorization and miss how these concepts relate to our everyday life and our society as a whole. Studying individual scientific disciplines are the vehicle for understanding cross-cutting concepts and acquiring scientific skills. When individual disciplines are studied within the context of practices and cross-cutting concepts they become more meaningful and more impactful.

For example: When looking for solutions to our current energy dependence it is not a problem to be solved by chemists or physicists or geologists independently. It can only be solved when scientists come together with an understanding of how their independent research relates to the larger problem at hand. If we focus solely upon a few facts or cool phenomenon we can overlook how the study of science can really improve and impact our society and personal experiences.

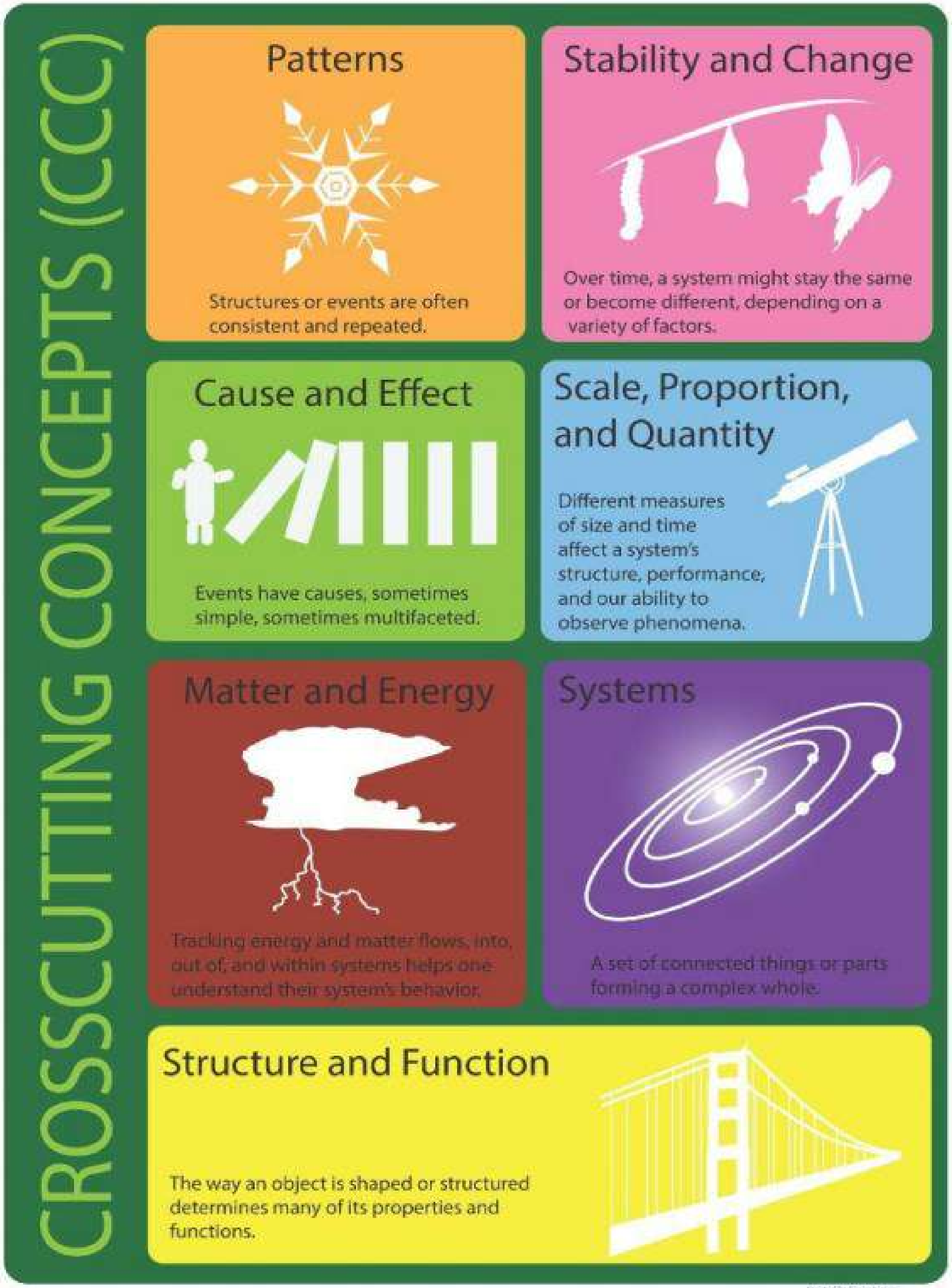
Science and Engineering Practices

Science and Engineering Practices are what scientists do to investigate and explore natural phenomena.



Cross Cutting Concepts

Crosscutting Concepts are the tools that scientists use to make sense of natural phenomena.



A Note to Teachers

This Open Educational Resource (OER) textbook has been written specifically for students as a reputable source for them to obtain information aligned to the Biology Science Standards. The hope is that as teachers use this resource with their students, they keep a record of their suggestions on how to improve the book. Every year, the book will be revised using teacher feedback and with new objectives to improve the book.

If there is feedback you would like to provide to support future writing teams please use the following online survey: http://go.uen.org/b62

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CHAPTER 1

Standard I: Energy Flow

Chapter Outline

Standard 1: Students will understand that living organisms interact with one another and their environment.

Objective 1: Summarize how energy flows through an ecosystem.

1. Arrange components of a food chain according to energy flow.
2. Compare the quantity of energy in the steps of an energy pyramid.
3. Describe strategies used by organisms to balance the energy expended to obtain food to the energy gained from the food (e.g., migration to areas of seasonal abundance, switching type of prey based upon availability, hibernation or dormancy).
4. Compare the relative energy output expended by an organism in obtaining food to the energy gained from the food (e.g., hummingbird - energy expended hovering at a flower compared to the amount of energy gained from the nectar, coyote - chasing mice to the energy gained from catching one, energy expended in migration of birds to a location with seasonal abundance compared to energy gained by staying in a cold climate with limited food).
5. Research food production in various parts of the world (e.g., industrialized societies' greater use of fossil fuel in food production, human health related to food product).

Objective 2: Explain relationships between matter cycles and organisms.

1. Use diagrams to trace the movement of matter through a cycle (i.e., carbon, oxygen, nitrogen, water) in a variety of biological communities and ecosystems.
2. Explain how water is a limiting factor in various ecosystems.
3. Distinguish between inference and evidence in a newspaper, magazine, journal, or Internet article that addresses an issue related to human impact on cycles of matter in an ecosystem and determine the bias in the article.
4. Evaluate the impact of personal choices in relation to the cycling of matter within an ecosystem (e.g., impact of automobiles on the carbon cycle, impact on landfills of processed and packaged foods).

Objective 3: Describe how interactions among organisms and their environment help shape ecosystems.

1. Categorize relationships among living things according to predator-prey, competition, and symbiosis.
2. Formulate and test a hypothesis specific to the effect of changing one variable upon another in a small ecosystem.
3. Use data to interpret interactions among biotic and abiotic factors (e.g., pH, temperature, precipitation, populations, diversity) within an ecosystem.
4. Investigate an ecosystem using methods of science to gather quantitative and qualitative data that describe the ecosystem in detail.
5. Research and evaluate local and global practices that affect ecosystems.

Unit Key Vocabulary

- Predator-prey
- Symbiosis
- Competition
- Ecosystem
- Carbon cycle
- Nitrogen cycle
- Oxygen cycle
- Population
- Diversity
- Energy pyramid
- Consumers
- Producers
- Limiting factor
- Competition
- Decomposers
- Food chain
- Biotic
- Abiotic
- Community
- Variable
- Evidence
- Inference
- Quantitative
- Qualitative

1.1 Flow of Energy

How Does Energy Flow Through an Ecosystem?

Am I all alone?

Do organisms live in isolation?

No, organisms are not separated from their environment or from other organisms. They interact in many ways with their surroundings. For example, this deer may be drinking from this stream or eating nearby plants. Ecology is the study of living (biotic) and nonliving (abiotic) interactions in an environment.

All organisms have the ability to grow and reproduce. To grow and reproduce, organisms must get materials and energy from the environment. Plants obtain their energy from the sun through photosynthesis, whereas animals obtain their energy from other organisms.

Either way, these plants and animals, as well as bacteria and fungi, are constantly interacting with other species as well as the nonliving parts of their ecosystem (the interaction of all of the living and nonliving parts of a community). An organism's environment includes two types of factors:

- Abiotic factors are the parts of the environment that are not living, such as sunlight, climate, soil, water, and air.
- Biotic factors are the parts of the environment that are alive, or were alive and then died, such as plants, animals, and their remains. Biotic factors also include bacteria, fungi and protists.

Ecology studies the interactions between biotic factors, such as organisms like plants and animals, and abiotic factors. For example, all animals (biotic factors) breathe in oxygen (abiotic factor). All plants (biotic factor) absorb carbon dioxide (abiotic factor) and need water (abiotic factor) to survive.

- Ecosystems can be studied at small levels or at large levels. The levels of organization are described below from the smallest to the largest:

- Individuals are members of the same species (a group of individuals who are genetically related and can breed to produce fertile offspring), if their members cannot produce offspring that can also have children. The second word in the two-word specific name given to every organism is the species name. For example, in *Homo sapiens*, *sapiens* is the species name and *Homo* is the genus.
- A population is a group of organisms belonging to the same species that live in the same area and interact with one another.
- A community is all of the populations of different species that live in the same area and interact with one another.
- An ecosystem includes the living (biotic) organisms (all the populations) in an area and the non-living (abiotic) aspects of the environment and their interactions.
- The biosphere in the figure below, is the highest level of ecological organization. It is the part of the earth, including the air, land, surface rocks, and water, where life is found and includes almost all of the Earth. Parts of the lithosphere, hydrosphere, and atmosphere make up the biosphere.

Ecologists study ecosystems at every level, from the individual organism to the whole ecosystem and biosphere. They can ask different types of questions at each level. Examples of these questions are given in the following below, using the zebra (*Equs zebra*) as an example.

Level	**Question**
Individual	How do zebras keep water in their bodies?
Population	What causes the growth of a zebra populations?
Community	How does a disturbance, like a fire or predator, affect the number of mammal species in African grasslands?
Ecosystem	How does fire affect the amount of food available in grassland ecosystems?
Biosphere	How does carbon dioxide in the air affect global temperature?

Summary

- Ecology is the study of how living organisms interact with each other and with their environment.
- Abiotic factors are the parts of the environment that have never been alive, while biotic factors are the parts of the environment that are alive, or were alive and then died.
- Levels of organization in ecology include individuals, species, populations, communities, ecosystems, and the biosphere.
- An ecosystem is all of the biotic factors in an area interacting with all of the abiotic factors of the environment.

Extension

Use the resource below to answer the questions that follow.

- A Study in Stream Ecology at USGS: http://go.uen.org/aYP

Think like an Ecologist

1. What are the levels of ecological organizations? Describe from largest to smallest.

2. What are some of the abiotic factors that scientists monitor when dealing with stream ecosystems?

3. What are some of the biotic factors that scientists monitor when dealing with stream ecosystems?

4. Why is it valuable for scientists to use the same procedures and gather the same information across different streams in many different areas? What does this allow them to do? How does this affect the strength and applicability of their research?

5. Pick your favorite cartoon or comic book story. Write a descriptive essay that illustrates the ecosystem they live in and what makes it unique. Be sure to describe the abiotic and biotic components, species, communities and interactions that would occur there.

Food Chains and Food Webs: Who's eating whom?

Objective

- Summarize how energy flows through an ecosystem through food chains and food webs.

Who eats whom?

To survive, one must eat. Why? To get energy! Food chains and webs describe the transfer of energy within an ecosystem, from one organism to another. In other words, they show who eats whom.

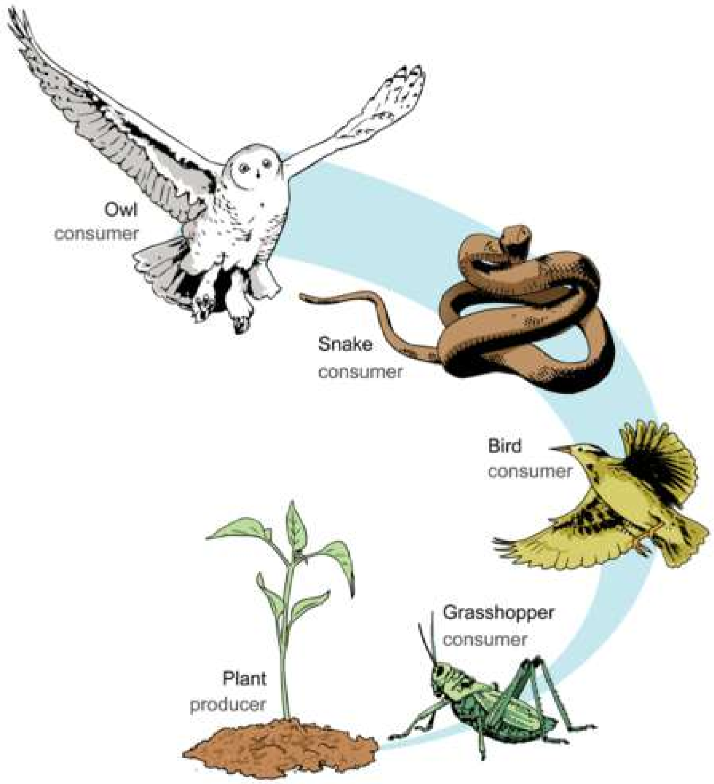
Food chains and food webs (diagrams that represent feeding relationships of different species) show who eats whom. In this way, they model how energy and matter move through ecosystems. Food chains always begin with producers (organisms that use a primary energy source (most commonly the sun) and photosynthesis, to make their own food / energy). The plants in the figure above are an example of producers.

Consumers (organisms that cannot make their own food and must get energy from other living organisms) can be herbivores, carnivores, or omnivores. Food chains might also include composers (organisms that get nutrients and energy by breaking down the remains of dead organisms or animal waste) such as bacteria and fungi. Through the process of decomposition, they recycle nutrients like carbon and nitrogen back into the environment so producers can use them.

Food for Thought

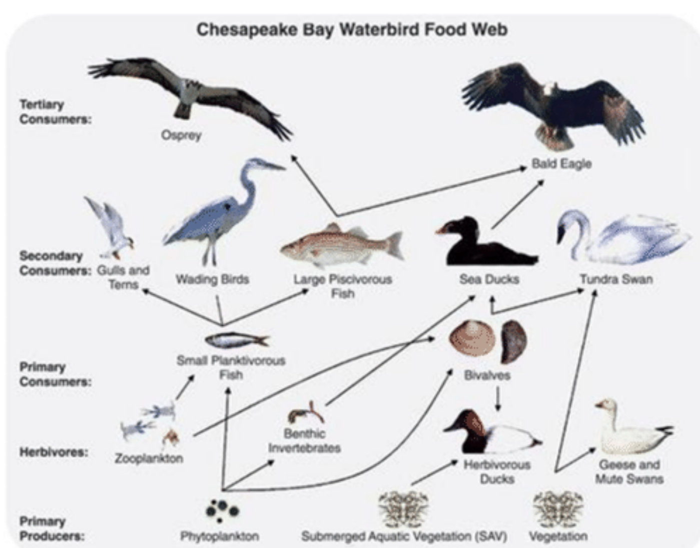
What would happen in an environment if there were no decomposers?

A food chain represents a single pathway by which energy and matter flow through an ecosystem. An example is shown in the Figure below. Food chains are generally simpler than what really happens in nature. Most organisms consume—and are consumed by—more than one species.



*https://www.ck12.org/biology/food-chain/lesson/Food-Chains-and-Food-Webs-Advanced-BIO-ADV/

- This food chain includes producers and consumers. How could you add decomposers to the food chain?
- Is the grasshopper shown in the food chain an herbivore, carnivore, or omnivore? How do you know?



This food web consists of several different food chains. Which organisms are producers in all of the food chains included in the food web?

A food web represents multiple pathways through which energy and matter flow through an ecosystem. It includes many intersecting food chains. It demonstrates that most organisms eat, and are eaten, by more than one species.

Activity: Draw one food chain out of the food web.

Summary

- Producers make their own food through photosynthesis.
- Consumers must obtain their nutrients and energy by eating other organisms.
- Decomposers break down animal remains and wastes to get energy.
- Food chains and food webs are diagrams that represent feeding relationships.
- Food chains and webs model how energy and matter move through ecosystems.

Extension

Use the resource below to answer the questions that follow.

- Decomposers at: http://go.uen.org/aYZ

Online Interactives/Simulations

Modeling Ecosystems Interactive Lab: Energy Flow through an ecosystem

- http://go.uen.org/aZ1

Food Chain Practice, Food Web Practice and Energy Pyramid Practice

- http://go.uen.org/aZ3
- http://go.uen.org/aZ6
- http://go.uen.org/aZ8

Think like an Ecologist

1. What type of relationships do food webs and food chains depict?
2. What is the role of decomposers in an ecosystem? What is the source of the matter that is decomposed?
3. How do the actions of earthworms improve soil quality? How does this impact the amount of living material an ecosystem can support?
4. How are food chains and food webs the same? How are they different?
5. There is going to be a zombie apocalypse. Only one producer can survive. It is your job to choose which producer survives. Explain which producer you would choose and why.

Energy Pyramids: Why do we have more warthogs than cheetahs?

Objective

- Explain how energy enters, is used, transferred and lost as it moves through organisms in an ecosystem.

How much energy can be gained from the warthog?

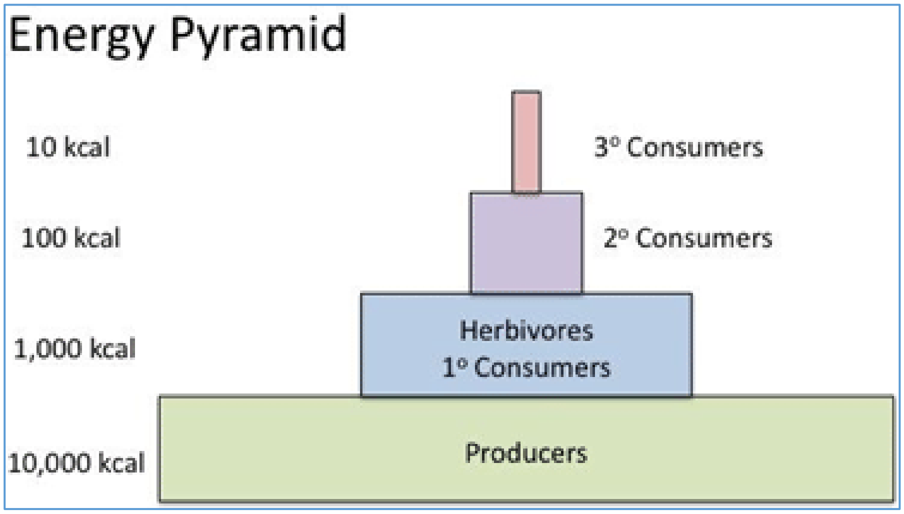
If the cheetah is successful in capturing the warthog, he would gain some energy by eating it. But would the cheetah gain as much energy as the warthog has ever consumed? No, the warthog has used up some of that energy for its own needs. The cheetah will only gain a fraction of the energy that the warthog has consumed throughout its lifetime.

When an herbivore eats a plant, the energy in the plant tissues is used by the herbivore. But how much of that energy is transferred to the herbivore? Remember that plants are producers, bringing the energy into the ecosystem by converting sunlight into glucose. The plant needs and uses much of that energy. After the plant uses the energy from glucose for its own needs, the excess energy is available to the organism that eats the plant.

The herbivore uses the energy from the plant to power its own life processes and to build more body tissues. However, only about 10% of the total energy from the plant gets stored in the herbivore's body as extra body tissue. The rest of the energy is used by the herbivore and released as heat. The next consumer on the food chain that eats the herbivore will only store about 10% of the total energy from the herbivore in its own body. This means the carnivore will store only about 1% of the total energy that was originally in the plant. In other words, only about 10% of energy of one step in a food chain is stored in the next step in the food chain. The majority of the energy is used by the organism or released to the environment.

Every time energy is transferred from one organism to another, there is a loss of energy. Energy is typically lost in the form of heat and respiration. This loss of energy can be shown in an energy pyramid. An example of an energy pyramid is shown in the Figure

below. Since there is energy loss at each step in a food chain, it takes many producers to support just a few carnivores in a community.



Each step of the food chain in the energy pyramid is called a trophic level. Plants or other photosynthetic organisms (autotrophs) are found on the first trophic level, at the bottom of the pyramid. The next level will be the herbivores, and then the carnivores that eat the herbivores. The energy pyramid in the Figure below shows four levels of a food chain, from producers to carnivores. Because of the high rate of energy loss in food chains, there are usually only 4 or 5 trophic levels in the food chain or energy pyramid. There just is not enough energy to support any additional trophic levels. Heterotrophs, organisms that cannot produce their own food, are found in all levels of an energy pyramid other than the first level. The first level is always occupied by producers, or autotrophs.

Summary

- Each time energy gets transferred within an ecosystem, some energy is lost, some gets used, and some gets stored.
- On average, only about 10% of the energy stored in an organism will be stored in the organism that eats it.

Online Interactives/Simulations

Lab Simulation: How is energy transferred through a community of organisms?

- http://go.uen.org/aZy

Think like an Ecologist

1. A warthog weighs 100 lbs. If a cheetah eats the warthog, approximately how many pounds will be used for energy by the cheetah?
2. What happens to the energy in the food that you eat when it gets into your body?
3. If the producers in an ecosystem were able to produce 10,000 kcal of energy through photosynthesis, about how much energy would be transferred to the first consumers

in the food chain? How much energy would transfer from producers to secondary consumers? How much would transfer from producers to tertiary consumers?

Energy: Is it worth it?

Objectives

- Describe how organisms balance the energy used to get food and the energy from the food.
- Provide examples of how food production varies worldwide.
- Describe strategies used by organisms to balance the energy expended to obtain food to the energy gained from food.

Why do animals behave the way they do? A cat chases a mouse to catch it. A mother dog nurses her puppies to feed them. All of these behaviors have the same purpose: getting or providing food. All animals need food for energy. They need energy to move around. In fact, they need energy just to stay alive. Energy allows all the processes inside cells to occur.

Why do spiders spin webs?

You have probably seen a spider web before. You may even know that spiders create webs to catch their prey. This is an example of animal behavior.

Organisms must balance the amount of energy they use to get food with the amount of energy they gain from the food. They have to decide if the prize is worth the effort. The spider shown above had to use a lot of energy to build his web, but hopefully he will be able to catch many insects before he builds a new one.

Food for Thought

If the spider uses 100 kcal to build his web, and each insect caught gives him an average of 20 kcal, how many insects does he need to catch before it's worth it to build the web?

Imagine that you had to run for an hour in order to get a candy bar. Would you do it? Probably not, because you would use more energy running than you would get from the candy bar. On the other hand, if you just had to walk around the block, it might be worth it. Hummingbirds have to use energy hovering at a flower in order to drink the nectar. They will only do it if they get more energy from the nectar than it takes to hover. A coyote will chase a rabbit to catch it, but only for so long. At some point, it's not worth it anymore because he has to use too much energy in the chase.

Animals have come up with many creative strategies to balance the energy used to obtain food with the energy gained from the food. One example is bird migration. The broad-tailed hummingbird pictured below is a common visitor to Utah in summertime. But these hummingbirds migrate all the way to Mexico for winter. Migration is a huge expenditure of energy, but the winters in Mexico are warmer, so the flowers continue to bloom and produce nectar for the birds to eat. Even though it is very difficult to fly so far, they are rewarded with plenty of available food, so the prize is worth the effort.

Some animals, such as this northern long-eared bat, hibernate during the winter because there is not a steady supply of available food. During hibernation, animals may carefully regulate their metabolism to slow it down and may also lower their core body temperature. Prior to hibernation, when food is plentiful, they eat in excess in order to store energy for the long period of inactivity during hibernation.

*https://commons.wikimedia.org/w/index.php?search=northern+bat&title=Special:Search&go=Go&searchToken=64um934349vzjuop4zaiqi48k#/media/File:Northern_long-eared_bat_(5881232758).jpg

Hibernation is one strategy that they use in order to balance their energy expenditures with their energy input from food.

Summary

- Organisms need to balance the amount of energy they use to get food with the amount of energy available in the food.
- Migration and hibernation are two examples of strategies animals use to balance their energy use with the energy gain from food.

Think like an Ecologist

1. If it took the same amount of energy to chase a mouse as it did to chase a rat, which do you think a cat would choose to chase? Why?
2. What is an example of a strategy used to balance energy used to obtain food with energy gained from the food (other than migration and hibernation)?
3. If there is a gas station a few miles from your house where the gas is $3.20 a gallon and one 15 miles away at $3.00 a gallon, which one do you go to?

Humans and Food: Where does my food come from?

Objective

- Investigate food production in various parts of the country and world.

Food production varies dramatically in different parts of the world. In many places, people can only eat the foods that are grown or caught locally. In other places, like the United States, we have access to food from all over the world.

How does this access to food affect us? How does it affect the world around us?

One major concern is the use of processed food, which has been changed from its original form, frequently stripping it of its nutritional value and adding in extra sugars and fats. Processed foods are very common in the United States and include things like toaster pastries, spreadable cheese, and hot dogs. These foods have many calories but little nutrient content, so they contribute to the obesity epidemic in America. Another concern related to food processing is the amount of fossil fuels that must be used in order to transport food from its source to the processing plants and eventually stores.

1.2 Matter Cycles and Organisms

Where did the matter in me come from?

Objective

- Use diagrams to trace the movement of matter through matter cycles in an ecosystem.

Matter Cycles

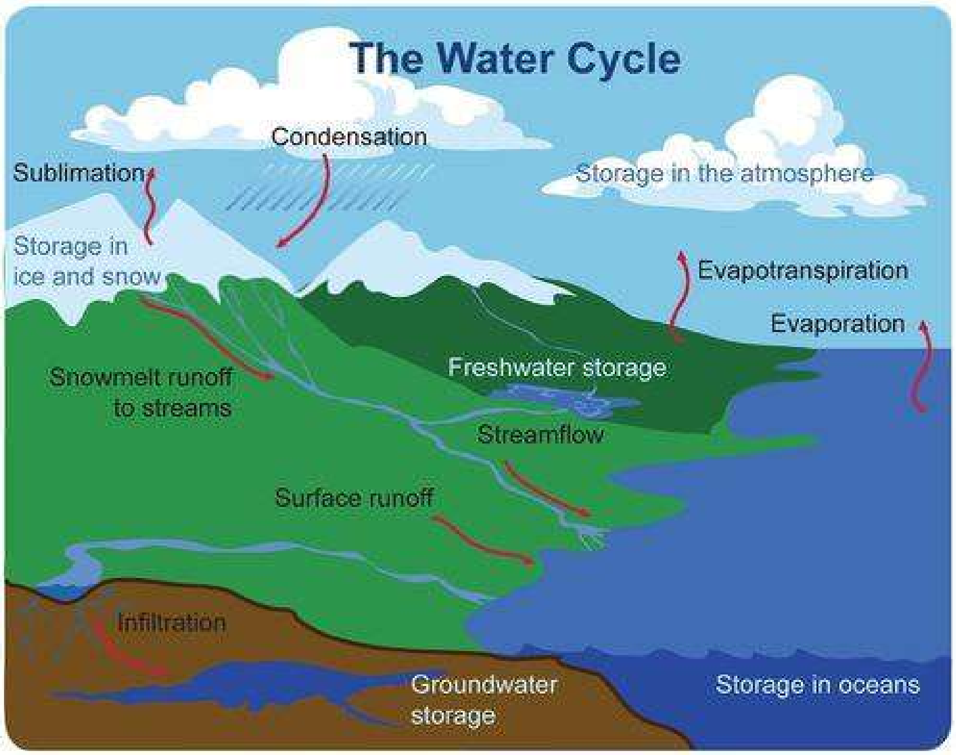
Unlike energy, matter is not lost as it passes through an ecosystem. Instead, matter, including water, is recycled. This recycling involves specific interactions between the biotic and abiotic factors in an ecosystem. Chances are, the water you drank this morning has been around for millions of years, or more. Water and nutrients are constantly being recycled through the environment. This process through which water or a chemical element is continuously recycled in an ecosystem is called a biogeochemical cycle.

For example, a chemical might move from organisms to the atmosphere or ocean and back to organisms again. Elements or water may be held for various periods of time in different parts of a cycle. This recycling process involves both the living organisms (biotic components) and nonliving things (abiotic factors) in the ecosystem. Through matter cycles, water and other chemical elements are constantly being passed through living organisms to nonliving matter and back again, over and over. Three important matter cycles are the water cycle, carbon cycle, and nitrogen cycle.

The Water Cycle: Where Did The Water I Am Drinking Come From?

The matter cycle that recycles water is the water cycle. The water cycle involves a series of interconnected pathways involving both the biotic and abiotic components of the biosphere. Water is obviously an extremely important aspect of every ecosystem. Life

cannot exist without water. Many organisms contain a large amount of water in their bodies, and many live in water, so the water cycle is essential to life on earth. Water continuously moves between living organisms, such as plants, and nonliving things, such as clouds, rivers, and oceans.



The water cycle does not have a real starting or ending point. It is an endless recycling process that involves the oceans, lakes and other bodies of water, as well as the land surfaces and the atmosphere.

During the water cycle, water occurs in three different states: gas (water vapor), liquid (water), and solid (ice). Many processes are involved as water changes state in the water cycle.

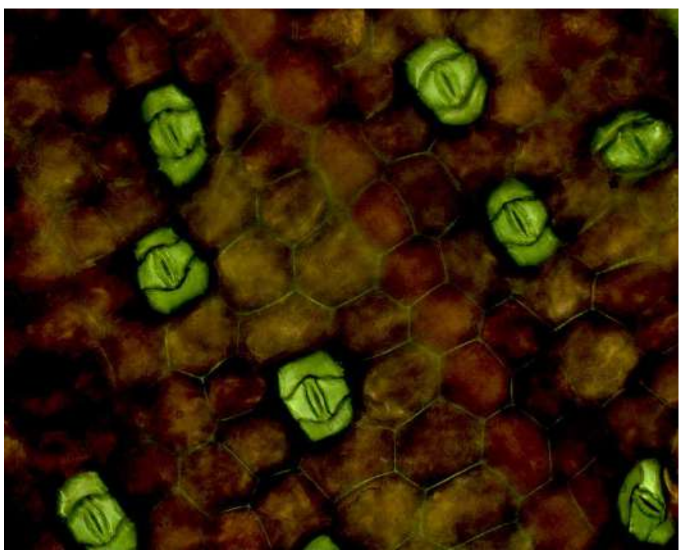
The steps in the water cycle are as follows, when starting with the water in the oceans (hydrosphere):

- Water evaporates from the surface of the oceans, leaving behind salts. As the water vapor rises, it collects and is stored in clouds.
- Water returns to the atmosphere through evaporation, transpiration (the process of water evaporating from the leaf of a plant), and sublimation (the process of water changing from a solid state to a gaseous state).
- As water cools in the clouds, condensation occurs. Condensation is when gases turn back into liquids.
- Condensation leads to precipitation. Precipitation includes rain, snow, hail, and sleet. The precipitation allows the water to return again to the Earth's surface.

- When precipitation lands on land, the water can sink into the ground to become part of our underground water reserves, also known as groundwater. Much of this underground water is stored in aquifers, which are porous layers of rock that can hold water.
- From groundwater, the water may be taken up by plant roots and enter the biosphere.
- Run-off.
- Most precipitation that occurs over land, however, is not absorbed by the soil and is called runoff. This runoff collects in streams and rivers and eventually flows back into the ocean.

Transpiration

Water also moves through the living organisms in an ecosystem. Plants soak up large amounts of water through their roots. The water then moves up the plant and evaporates from tiny openings (See Figure) in the leaves in a process called transpiration. The process of transpiration, like evaporation, returns water back into the atmosphere.



*https://commons.wikimedia.org/w/index.php?search=stomata&title=Special:Search&profile=default&fulltext=1&searchToken=1yiv5tvia76dmonyvaiyqdbqn#/media/File:Zebrina_stomata.jpeg

Plant leaves have many tiny stomata. They release water vapor into the air.

Extension

Check out the following website for more details about the water cycle.

- http://go.uen.org/aZN

Check out the following website to see how scientists are studying the recycling of water.

- http://go.uen.org/aZP

Summary

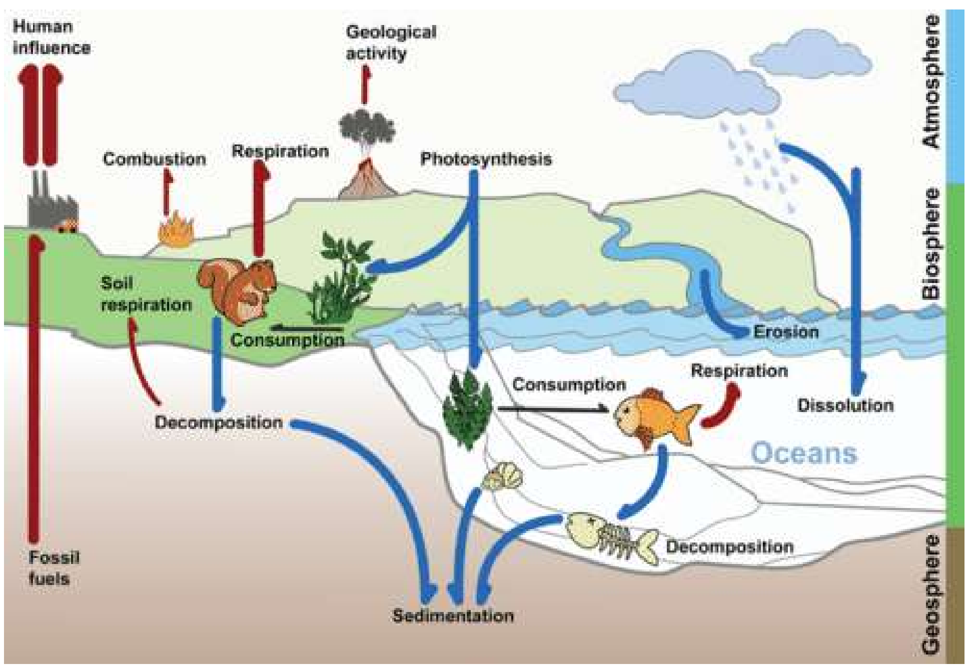
- Chemical elements and water are constantly recycled in the ecosystem through matter cycles.
- During the water cycle, water enters the atmosphere by evaporation and transpiration, and water returns to land by precipitation.

Thinking like a Hydrologist

1. Why are matter cycles called cycles?
2. What is the name of the process by which water returns to land from the atmosphere?
3. What are two processes by which water returns to the atmosphere from land?
4. Draw a diagram showing how the water cycle might affect one population of land animals. How would this compare to the water used by plants?

The Carbon Cycle: What do I and Campfire Smoke have in Common?

Carbon is one of the most common elements found in living organisms. Chains of carbon molecules form the backbones of many molecules, such as carbohydrates, proteins, and lipids. Carbon is constantly cycling between living organisms and the atmosphere. The cycling of carbon occurs through the carbon cycle.



The carbon cycle

Living organisms cannot make their own carbon, so how is carbon incorporated into living organisms? In the atmosphere, carbon is in the form of carbon dioxide gas (CO_2). Recall that plants and other producers capture the carbon dioxide and convert it to glucose ($C_6H_{12}O_6$) through the process of photosynthesis. Then as animals eat plants or other animals, they gain the carbon from those organisms.

The chemical equation of photosynthesis is:

$$6CO_2+6H_2O \rightarrow C_6H_{12}O_6+6O_2$$

The chemical equation of respiration is:

$$C_6H_{12}O_6+6O_2 \rightarrow 6CO_2+6H_2O$$

Food for Thought

How might the carbon cycle now be different from the carbon cycle of 1000 years ago?

How does this carbon in living things end up back in the atmosphere? Remember that we breathe out carbon dioxide. This carbon dioxide is generated through the process of cellular respiration, which has the reverse chemical reaction as photosynthesis. That means when our cells burn food (glucose) for energy, carbon dioxide is released. We, like all animals, exhale this carbon dioxide and return it back to the atmosphere. Also, carbon is released to the atmosphere as an organism dies and decomposes.

The cycling of carbon dioxide in photosynthesis and cellular respiration are main components of the carbon cycle. Carbon is also returned to the atmosphere by the burning of fossil fuels and decomposition of organic matter. This means that human activities such as burning gasoline in cars or using coal and wood are releasing more carbon into the atmosphere. This acts as a greenhouse gas and has been linked to global environmental change.

Summary

- During the carbon cycle, animals and plants add carbon dioxide to the atmosphere through cellular respiration, and plants remove carbon dioxide through photosynthesis.
- The burning of fossil fuels releases more carbon dioxide into the atmosphere, contributing to global climate change.

Online Interactives/Simulations

Carbon Cycle Interactive Science and Global Issues

- http://go.uen.org/aZS

Carbon Cycle Game – Trace a carbon atom

- http://go.uen.org/aZT

Annenberg Learner – Links to several interactive carbon labs with feedback effect

- http://go.uen.org/aZV

Ecological Footprint calculator Earth Day Network

- http://go.uen.org/aZW

Think like an Ecologist

1. Summarize the carbon cycle by drawing a diagram, including the role of plants, animals, and fossil fuels, and the terms photosynthesis and cellular respiration.

2. List three ways that you can personally decrease your contribution to global environmental change.

3. Rio Tinto Kennecott Copper has affected the ecosystems in Utah. Find both pros and cons in your assessment. You can use their website: http://go.uen.org/aZX should Rio Tinto make any changes to how they run their business?

The Nitrogen Cycle: Why do we use fertilizers?

What can bean plants do that most other plants can't?

No, they don't grow giant stalks to the clouds. Bean plants and other legumes (plants that have their seeds in pods) can use the nitrogen in the air to grow. It takes the help of special bacteria friends in the soil, and this relationship is unique to the legumes.

Like water and carbon, nitrogen is also repeatedly recycled through the biosphere. This process is called the nitrogen cycle. Nitrogen is one of the most common elements in living organisms. It is important for creating both proteins and nucleic acids, like DNA. The air that we breathe is mostly nitrogen gas (N_2), but, unfortunately, animals and plants cannot use the nitrogen when it is a gas. In fact, plants often die from a lack of nitrogen even though they are surrounded by plenty of nitrogen gas. Nitrogen gas (N_2) has two nitrogen atoms connected by a very strong triple bond. Most plants and animals cannot use the nitrogen in nitrogen gas because they cannot break that triple bond.

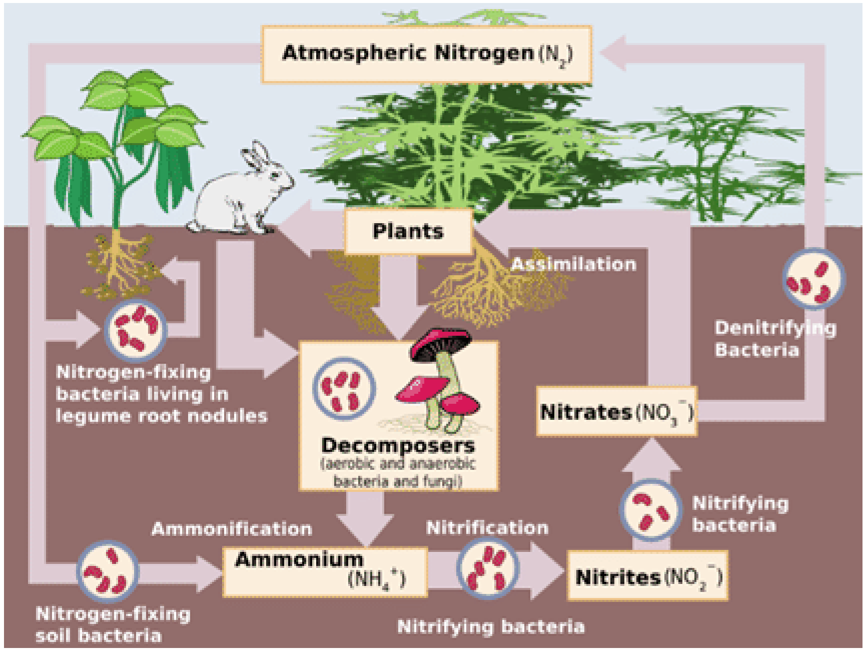
In order for plants to make use of nitrogen, it must be transformed into molecules they can use. This can be accomplished several different ways:

Lightning: Nitrogen gas can be transformed into nitrate (NO_3^-) that plants can use when lightning strikes.

Nitrogen fixation: Special nitrogen-fixing bacteria can also transform nitrogen gas into useful forms. These bacteria live in the roots of plants in the pea (legume) family. They turn the nitrogen gas into ammonium (NH_4^+). In water environments, bacteria in the water can also fix nitrogen gas into ammonium. Ammonium can be used by aquatic plants as a source of nitrogen.

Nitrogen also is released to the environment by decaying organisms or decaying wastes. These wastes release nitrogen in the form of ammonium.

Ammonium in the soil can be turned into nitrate by a two-step process completed by two different types of bacteria. In the form of nitrate, nitrogen can be used by plants through the process of assimilation. It is then passed along to animals when they eat the plants.



Sending nitrogen back to the atmosphere

Turning nitrate back into nitrogen gas, the process of denitrification, happens through the work of denitrifying bacteria. These bacteria often live in swamps and lakes. They take in the nitrate and release it back to the atmosphere as nitrogen gas.

Did You Know?

The Three Sisters are the three main agricultural crops of various Native American groups in North America: squash, maize (corn), and climbing beans.

In one technique known as companion planting, the three crops are planted close together.

The three crops benefit from each other. The maize provides a structure for the beans to climb, eliminating the need for poles. The beans provide the nitrogen to the soil that the other plants utilize, and the squash spreads along the ground, blocking the sunlight, helping prevent establishment of weeds.

Native Americans throughout North America are known for growing variations of Three Sisters gardens.

The Three Sisters planting method is featured on the reverse of the 2009 US Sacagawea Native American dollar coin.

Just like the carbon cycle, human activities impact the nitrogen cycle. These human activities include the burning of fossil fuels, which release nitrogen oxide gas into the atmosphere. Releasing nitrogen oxide back into the atmosphere leads to problems like acid rain.

Summary

- Gaseous nitrogen is converted into forms that can be used by plants during the process of nitrogen fixation.
- Denitrifying bacteria turn nitrate back into gaseous nitrogen.

Online Interactive/Simulations

Interactive Nitrogen Cycle

- http://go.uen.org/b00

Think Like an Environmental Scientist

1. Why do we use nitrogen in fertilizers?

2. Why can't plants and animals use the nitrogen gas in the air?

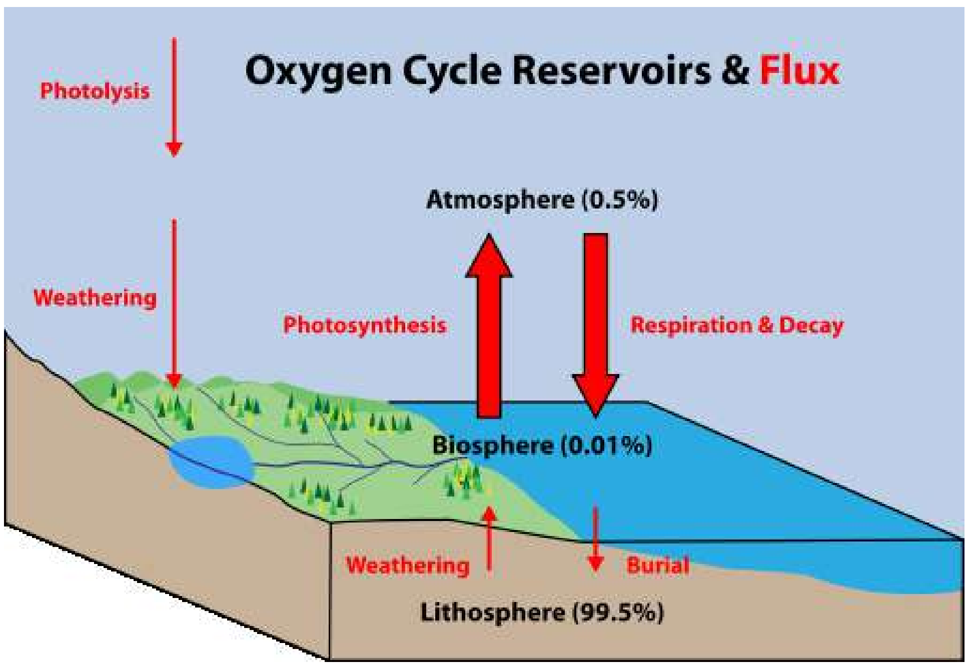
3. What are three ways that nitrogen gas can be converted into a usable form?

4. You are planting a garden, which types of plants should you use in order to not have to use fertilizers? Explain in complete sentences.

The Oxygen Cycle: How do I cycle oxygen?

The oxygen cycle is the matter cycle that describes the movement of oxygen within its three main reservoirs: the atmosphere (air), all living matter within the biosphere (the global sum of all ecosystems), and the lithosphere (Earth's crust). See the next figure.

The main driving factor of the oxygen cycle is photosynthesis, which is responsible for the modern Earth's atmosphere and life as we know it. The released oxygen is primarily converted back to carbon dioxide through the respiration of organisms. However, the majority of all oxygen is trapped in the ground in the earth's lithosphere. Refer to the figure below.



*https://en.wikipedia.org/wiki/Oxygen_cycle#/media/File:Oxygen_cycle.svg

The Oxygen Cycle

The presence of atmospheric oxygen has led to the formation of ozone (O_3) and the ozone layer within the stratosphere. The ozone layer is extremely important to modern life as it absorbs harmful ultraviolet radiation.

Summary

- Oxygen is added to the atmosphere through photosynthesis.
- In the atmosphere, some oxygen is converted to ozone, a molecule that absorbs ultraviolet light, protecting us from harmful rays.
- Oxygen is taken out of the atmosphere by living things and is used during cellular to release energy from sugars. The living things then release carbon dioxide back into the environment.

Think like a Scientist

1. How does the CO_2 I breathe out become oxygen?

2. Where does the oxygen gas in our atmosphere come from?

3. What is the role of ozone in our atmosphere?

4. How have human activities played a role in the cycling of oxygen?

Limiting Factors and Population Growth: How many mice can I fit in my pocket?

Objectives

- Explain how limiting factors affect the amount of resources available to an ecosystem.
- For a population to be healthy, factors such as food, nutrients, water and space, must be available. What happens when there are not resources to support the population? Limiting factors are resources or other factors in the environment that can lower the population growth rate. Limiting factors include a low food supply and lack of space. Limiting factors can lower birth rates, increase death rates, or lead to emigration.

If there are 12 hamburgers at a lunch table and 24 people sit down at a lunch table, will everyone be able to eat? At first, maybe you will split hamburgers in half, but if more and more people keep coming to sit at the lunch table, you will not be able to feed everyone. This is what happens in nature. But in nature, organisms that cannot get food will die or find a new place to live. It is possible for any resource to be a limiting factor (environmental conditions that influence the growth, distribution, and abundance of a population), a resource such as food can have dramatic consequences on a population.

In nature, when the population size is small, there is usually plenty of food and other resources for each individual. When there is plenty of food and other resources, organisms can easily reproduce, so the birth rate is high. As the population increases, the food supply, or the supply of another necessary resource, may decrease. When necessary resources, such as food, decrease, some individuals will die. Overall, the population cannot reproduce at the same rate, so the birth rates drop. This will cause the population growth rate to decrease.

When the population decreases to a certain level where every individual can get enough food and other resources, and the birth and death rates become stable, the population has leveled off at its carrying capacity.

Other Limiting Factors

Other limiting factors include light, water, nutrients or minerals, oxygen, the ability of an ecosystem to recycle nutrients and/or waste, disease and/or parasites, temperature, space, and predation. Can you think of some other factors that limit populations?

In desert states, such as Utah, water is crucial for crop growth and local animal populations, and in this way is a limiting factor for population growth of certain plant and animal species. Watershed areas are set up to catch spring runoff in reservoirs for use throughout the Intermountain West.

The opposite situation can also be true: too much water can be a limiting factor in certain ecosystems. Whereas most plants like rain, an individual cactus-like the *Agave americana* plant actually likes to grow when it is dry. Rainfall limits reproduction of this plant which, in turn, limits growth rate. Can you think of some other factors like this?

Human activities can also limit the growth of populations. Such activities include use of pesticides and habitat destruction.

Summary

- Limiting factors are resources or other factors in the environment that limit population growth. They include food, water, habitat, and other similar resources.
- Populations can only grow bigger when their needs for nutrients and other resources are met. The carrying capacity of a habitat is the maximum population that it can support.

Think like an Ecologist

1. Why is it that populations are limited in size?
2. What factors keep populations from reaching their carrying capacity?
3. How do you think the length of an organism's life span will affect the species' ability to reach carrying capacity?
4. Give three examples of limiting factors in an environment and explain why each one can be limiting.
5. You are a wildlife biologist in charge of managing Utah’s elk population. During the summer you conduct some research and discover that the herd is well over the carrying capacity. What are some consequences if the population remains high? How can you prevent those consequences from happening?

1.3 Ecosystems

How do interactions among organisms and their environment help shape ecosystems?

A commensal shrimp on another sea organism, possibly a sea cucumber.

Some organisms play nice. Some don't. Some play nice with certain organisms while playing not so nice with others. Regardless, many organisms have close living relationships that can be characterized.

Humans, like nature, have many types of relationships. Let's examine the relationships of Superman. Superman has many relationships in his life. Lois Lane loves Superman and protects his secret while Superman loves and protects her—a mutualistic relationship. Lex Luthor is always looking to attack and hurt Superman—a predator-prey like relationship. We all know Superman's weakness is kryptonite, which pulls away his power and can, with long-term exposure, kill him—a parasitic relationship. Lastly, Lois Lane and Lex Luthor share a relationship where Lex benefits because he can use Lois to draw in Superman, serving as a benefit for Lex, but neither help nor harm Lois—a commensalistic relationship.

Symbiosis is a close relationship between two species in which at least one species benefits. For the other species, the relationship may be positive, negative, or neutral. There are three basic types of symbiosis:

- Mutualism
- Commensalism
- Parasitism

Mutualism is a symbiotic relationship in which both species benefit. An example of mutualism involves goby fish and shrimp (see the figure on the next page).

The multi colored shrimp in the front and the green goby fish behind it have a mutualistic relationship.

The nearly blind shrimp and the fish spend most of their time together. The shrimp maintains a burrow in the sand in which both the fish and shrimp live. When a predator comes near, the fish touches the shrimp with its tail as a warning. Then, both fish and shrimp retreat to the burrow until the predator is gone. From their relationship, the shrimp gets a warning of approaching danger. The fish gets a safe retreat and a place to lay its eggs.

Commensalism is a symbiotic relationship in which one species benefits while the other species is not affected. One species typically uses the other for a purpose other than food. For example, mites attach themselves to larger flying insects to get a "free ride." Hermit crabs use the shells of dead snails for homes.

Parasitism is a symbiotic relationship in which one species (the parasite) benefits while the other species (the host) is harmed. Many species of animals are parasites, at least during some stage of their life. Most species are also hosts to one or more parasites. Some parasites live on the surface of their host. Others live inside their host. They may enter the host through a break in the skin or in food or water. For example, roundworms are parasites of mammals, including humans, cats, and dogs.

The worms produce huge numbers of eggs, which are passed in the host's feces to the environment. Other individuals may be infected by swallowing the eggs in contaminated food or water. The roundworm above, found in a puppy's intestine, might eventually fill a dog's intestine unless it gets medical treatment.

Some parasites kill their host, but most do not. It's easy to see why. If a parasite kills its host, the parasite is also likely to die. Instead, parasites usually cause relatively minor damage to their host.

Summary

- Symbiosis is a close relationship between two species in which at least one species benefits.
- Mutualism is a symbiotic relationship in which both species benefit.
- Commensalism is a symbiotic relationship in which one species benefits while the other species is not affected.
- Parasitism is a symbiotic relationship in which one species (the parasite) benefits while the other species (the host) is harmed.

Think like an Ecologist

1. What are the three types of symbiotic relationships?
2. Describe the three symbiotic relationships.
3. Describe an example of a symbiotic relationship involving humans.
4. Describe a symbiotic relationship involving plants and bacteria.
5. Define mutualism and commensalism.
6. Explain why most parasites do not kill their host. Why is it in the best interest of a parasite to keep its host alive?

Predator-Prey: Who's in charge here?

Can insects hunt for food? When you think of an animal hunting for its food, large animals such as lions may come to mind. But many tiny animals also hunt for their food. For example, this praying mantis is eating a grasshopper. To eat the grasshopper, the praying mantis first had to catch the grasshopper, which is a form of hunting.

Predation is another mechanism in which species interact with each other. Predation is when a predator organism feeds on another living organism or organisms, known as prey. The predator always lowers the prey's fitness. It does this by keeping the prey from surviving, reproducing, or both .Predator-prey(relationship where one species, the predator, eats or consumes another species, the prey) relationships are essential to maintaining the balance of organisms in an ecosystem.

There are different types of predation, including:

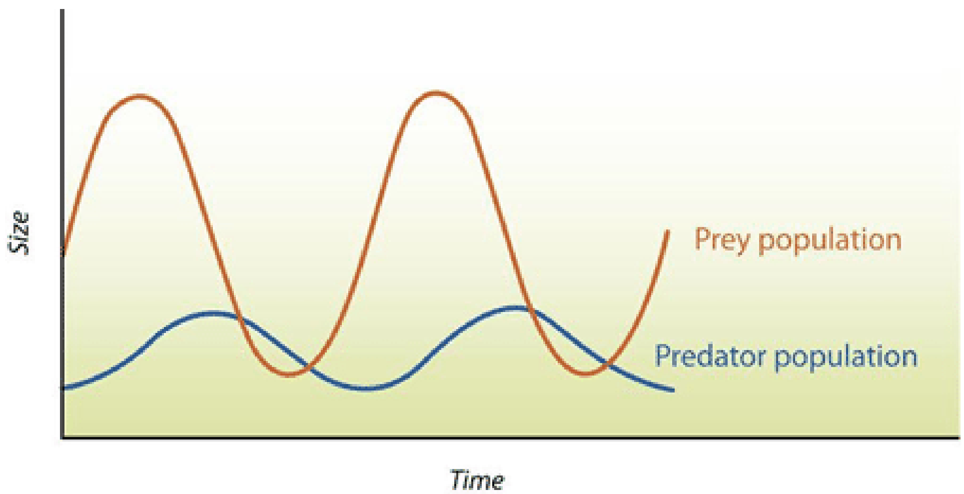
- Predation (True Predation)
- Grazing
- Parasitism

Predation is when a predator kills and eats its prey. Some predators of this type, such as jaguars, kill large prey. They tear it apart and chew it before eating it. Others, like bottlenose dolphins or snakes, may eat their prey whole. In some cases, the prey dies in the mouth or the digestive system of the predator. Baleen whales, for example, eat millions of plankton at once. The prey is digested afterward. Predators may hunt actively for prey, or they may sit and wait for prey to get within striking distance.

This example of a true predator shows a pair of lions actively hunting prey.

In grazing, the predator eats part of the prey but does not usually kill it. You may have seen cows grazing on grass. The grass they eat grows back, so there is no real effect on the population. In the ocean, kelp (a type of seaweed) can regrow after being eaten by fish.

Predators play an important role in an ecosystem. For example, if they did not exist, then a single species could become dominant over others. Grazers on a grassland keep grass from growing out of control. There are species that can have a large effect on the balance of organisms in an ecosystem. For example, if all of the wolves are removed from a population, then the population of deer or rabbits may increase. If there are too many deer, then they may decrease the amount of plants or grasses in the ecosystem. Decreased levels of producers may then have a detrimental effect on the whole ecosystem.



A predator-prey relationship tends to keep the populations of both species in balance. This is shown by the graph in the figure below. As the prey population increases, there is more food for predators. So, after a slight lag, the predator population increases as well. As the number of predators increases, more prey are captured. As a result, the prey population starts to decrease. What happens to the predator population then?

Summary

- Predation happens when a predator organism feeds on another living organism or organisms, known as prey.
- Predator-prey relationships help keep populations in balance.

Online Interactive Activity

Dragonfly Larva Hunts Newt at Shape of Life Video.

- http://go.uen.org/b0v

Think Like a Field Ecologist

1. How do you determine which organism is the prey and which one is the predator?

2. What are some of the effects predation has on ecosystems and ecosystem dynamics?

3. What is the difference between a lion's predation and a cow's predation?

4. The amount of prey has increased in a population, what will happen to the amount of predators? Why? Explain in one paragraph using full sentences.

Competition: Does there have to be a winner?

Does there have to be a winner? When animals compete, yes. Animals, or other organisms, will compete when both want the same thing. One must "lose" so the winner can have the resource. But competition doesn't necessarily involve physical altercations.

Competition (a relationship between organisms that strive for the same resources in the same place) can be for resources such as food, water, or space. There are two different types of competition:

- Competition between members of the same species (intraspecific competition). For example, two male birds of the same species might compete for mates in the same area. This type of competition is a basic factor in natural selection. It leads to the evolution of better adaptations within a species.
- Competition between members of different species (interspecific competition). For example, predators of different species might compete for the same prey.

Instead of extinction, interspecific competition may lead to greater specialization of a niche. Specialization occurs when competing species evolve different adaptations. For example, they may evolve adaptations that allow them to use different food sources. The following figure describes an example.

Specialization lets different species of anole lizards live in the same area without competing.

Summary

- Competition is a relationship between organisms that strive for the same resources in the same place.
- Intraspecific competition occurs between members of the same species. It improves the species' adaptations.
- Interspecific competition occurs between members of different species. It may lead to one species going extinct or both becoming more specialized.

Online Interactives

Use a model to study the effect of a consumer (rabbits) on two species of producers (Grass & Weeds)

- http://go.uen.org/b1u

Predator Prey simulation: Population density dependent factor in population growth

- http://go.uen.org/b1v

Predator Prey interactions and Invasive Species

- http://go.uen.org/b1w

Think like an Ecologist

1. Create a list of at least 4 resources that lead to competition of organisms.

2. Is competition always between different species?

CHAPTER 2

Standard 2: Cells

Chapter Outline

Standard 2: Students will understand that all organisms are composed of one or more cells that are made of molecules, come from preexisting cells, and perform life functions.

Objective 1: Describe the fundamental chemistry of living cells.

1. List the major chemical elements in cells (i.e., carbon, hydrogen, nitrogen, oxygen, phosphorus, sulfur, trace elements).
2. Identify the function of the four major macromolecules (i.e., carbohydrates, proteins, lipids, nucleic acids).
3. Explain how the properties of water (e.g., cohesion, adhesion, heat capacity, solvent properties) contribute to maintenance of cells and living organisms.
4. Explain the role of enzymes in cell chemistry.

Objective 2: Describe the flow of energy and matter in cellular function.

1. Distinguish between autotrophic and heterotrophic cells.
2. Illustrate the cycling of matter and the flow of energy through photosynthesis (e.g., by using light energy to combine CO_2 and H_2O to produce oxygen and sugars) and respiration (e.g., by releasing energy from sugar and O_2 to produce CO_2 and H_2O).
3. Measure the production of one or more of the products of either photosynthesis or respiration.

Objective 3: Investigate the structure and function of cells and cell parts.

1. Explain how cells divide from existing cells.
2. Describe cell theory and relate the nature of science to the development of cell theory (e.g., built upon previous knowledge, use of increasingly more sophisticated technology).
3. Describe how the transport of materials in and out of cells enables cells to maintain homeostasis (i.e., osmosis, diffusion, active transport).
4. Describe the relationship between the organelles in a cell and the functions of that cell.
5. Experiment with microorganisms and/or plants to investigate growth and reproduction.

Unit Key Vocabulary

- Organelles
- Photosynthesis
- Respiration
- Cellular Respiration
- Osmosis
- Diffusion
- Active Transport
- Homeostasis
- Cell Theory
- Organic
- Carbohydrate
- Fermentation
- Protein
- Fat
- Nucleic Acid
- Enzyme
- Chlorophyll
- Cell Membrane
- Nucleus
- Cell Wall
- Solvent
- Solute
- Adhesion
- Cohesion
- Microorganism

2.1 Components of Matter

What are you made of?

Objective

- List the major chemical elements in cells (i.e. carbon, hydrogen, nitrogen, oxygen, phosphorus, sulfur, trace elements)

Introduction

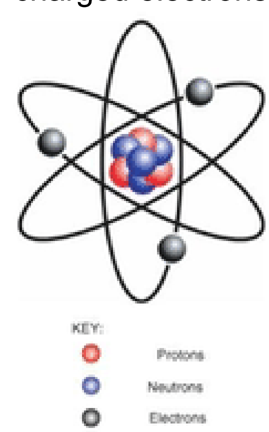
Living things are made of matter. In fact, matter is the "stuff" of which all things are made. Anything that occupies space and has mass is known as matter. Matter, in turn, consists of chemical substances.

Chemical Substances

A chemical substance is a material that has a definite chemical composition. It is also homogeneous, so the same chemical composition is found uniformly throughout the substance. A chemical substance may be an element or a chemical compound.

Elements

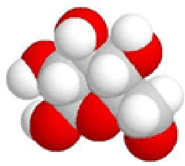
Each element is made up of just one type of atom. An atom is the smallest particle of an element that still characterizes the element. As shown in the figure, at the center of an atom is a nucleus. The nucleus contains positively charged particles called protons and electrically neutral particles called neutrons. Surrounding the nucleus is a much larger electron cloud consisting of negatively charged electrons.



Model of an Atom. The protons and neutrons of this atom make up its nucleus. Electrons surround the nucleus.

KEY: Red = protons, Blue = neutrons, Black = electrons.

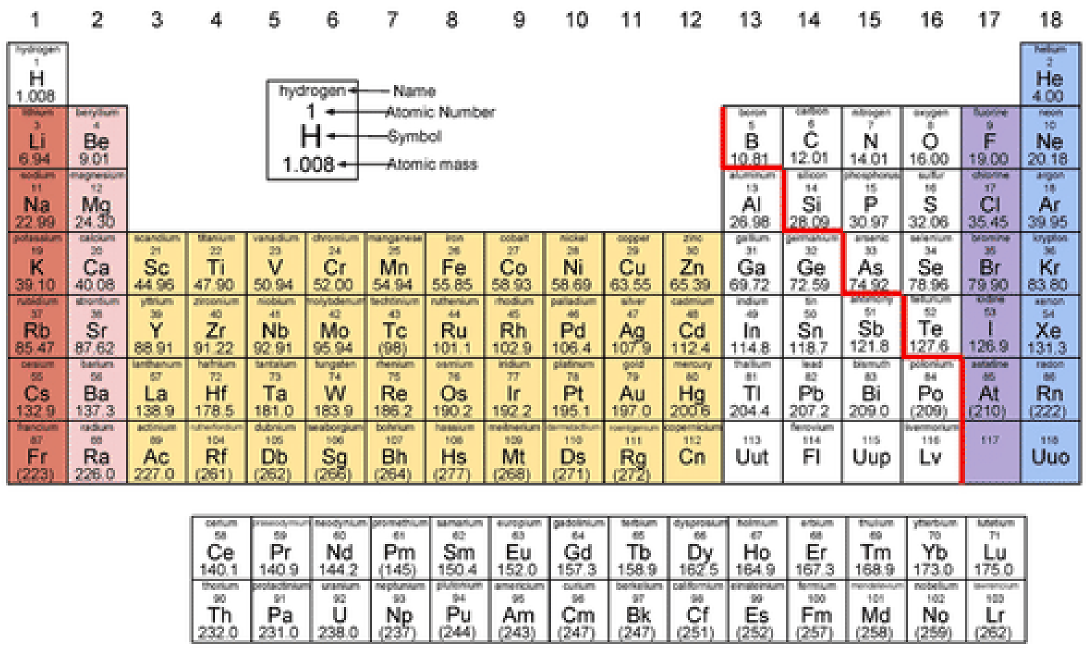
Elements include carbon, oxygen, hydrogen, and iron. The most abundant elements in cells are carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur. The acronym CHNOPS can be used to remember these elements. These elements are what make up the majority of living things.



Trace elements are elements that are required by living things in small amounts, but play a part in helping the body function properly. An example of a trace element is iron. Iron is used in red blood cells to carry oxygen.

"Meet the Elements" song: Listing major elements of life, composition of atom and how compounds are formed.

YouTube Video: http://go.uen.org/b2x



Summary

- Matter consists of elements. The most abundant elements in living things are carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur. Trace elements also play key roles in organisms. Online Interactives/Simulations

Interactive periodic table of elements

- http://go.uen.org/b2y

Think like a Biochemist

1. What are the major chemical elements that you are composed of?

2. Define element, and give an example of an element.

Macromolecules: Are You What You Eat?

Objective

- Identify the function of the four major macromolecules (i.e. carbohydrates, proteins, lipids, nucleic acids).

Introduction

A chemical compound is a new substance that forms when atoms of two or more elements react with one another. Compounds that contain carbon are called organic.

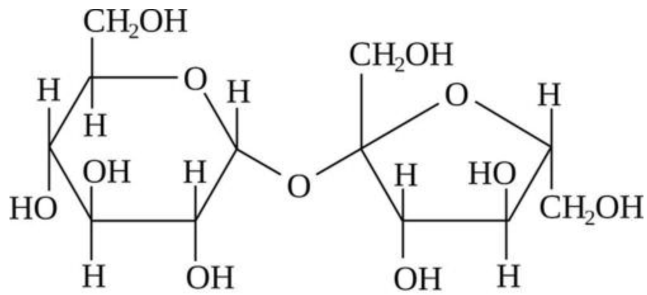
Macromolecules

Large organic molecules known as macromolecules, are composed of smaller organic molecules linked together. There are four classes of macromolecules: carbohydrates, lipids, proteins, and nucleic acids.

Macros	Functions	Elements it Contains	Examples
Carbohydrates	primary source of energy	Carbon, Hydrogen, Oxygen	Pasta, cereal, fruits, vegetables
Lipids	long term energy storage, component of cell membranes	Carbon, Hydrogen, Oxygen	Fats, oils, waxes, steroids, hormones
Proteins	provides cell structure, Speed up chemical reactions (enzymes)	Carbon, Hydrogen, Oxygen, Nitrogen, Sulfur	Muscle, enzymes
Nucleic Acids	Carry genetic information	Carbon, Hydrogen, Oxygen, Nitrogen, Phosphorus	DNA, RNA

Carbohydrates

Carbohydrates (organic compounds such as sugars and starches that provide quick energy) contain only carbon, hydrogen, and oxygen and are the most common of the four major types of macromolecules.



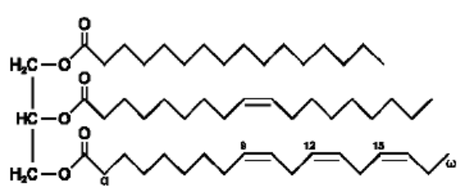
Sucrose Molecule. This sucrose molecule is made up of glucose on the left and fructose on the right.

Carbohydrates and Diet

Carbohydrates include the sugars and starches. Sugars include sucrose (table sugar), fructose (the sugar found in fruit) and lactose (the sugar found in milk). Starches like potatoes and pasta are common foods in our diet. Long distance runners utilize carbohydrates to give them a reserve of energy for their race. Runners may "carb load" which means that they will eat a lot of carbohydrates (such as pasta) before a big race.

Lipids

Lipids are organic compounds that include the fat, oils and waxes and provides a long-term energy source for organisms. They contain carbon (C), hydrogen (H) and oxygen (O). Examples of fats in a diet include cooking oils such as sunflower and olive oil, butter, margarine, and lard. Many nuts and seeds also contain a high proportion of lipids. As the main long-term energy storage of an organisms they contain about twice the energy per gram compared to a gram of protein or carbohydrates.



*https://commons.wikimedia.org/wiki/File:Fat_triglyceride_shorthand_formula.PNG

A Lipid Molecule (triglyceride)

Types of Lipids and their Functions

- Triglycerides are the main form of stored energy in animals. This type of lipid is commonly called fat. Phospholipids are a major component of the membranes surrounding the cells of all organisms.
- Steroids (or sterols) have several functions. The sterol cholesterol is an important part of cell membranes and plays other vital roles in the body. Other steroids are male and female sex hormones.

Fats and Diet

Humans need fats for many vital functions, such as storing energy and forming cell membranes. Fats can also supply cells with energy. A gram of fat supplies more than twice as much energy as a gram of carbohydrates or proteins. Fats are necessary in the diet for most of these functions. Although the human body can manufacture most of the lipids it needs there are others called essential fatty acids that must be consumed in food.

Proteins

Proteins include enzymes, antibodies and muscle fibers containing carbon, hydrogen, oxygen, nitrogen, and, in some cases, sulfur. Proteins are made of smaller units called amino acids. There are 20 different common amino acids needed to make proteins.

Amino acids can bond together to form chains of differing lengths. (. The sequence of amino acids in a protein's chain(s) determines the overall structure and chemical properties of the protein.

Functions of Proteins

Proteins are an essential part of all organisms. They play many roles in living things. Certain proteins provide a scaffolding that maintains the shape of cells. Proteins also make up the majority of muscle tissues. Many proteins are enzymes that speed up chemical reactions in cells. Other proteins are antibodies. They bond to foreign substances in the body and target them for destruction (see the Immune System and Disease section of Chapter 3). Still other proteins help carry messages or materials in and out of cells or around the body. For example, the blood protein hemoglobin bonds with oxygen and carries it from the lungs to cells throughout the body.

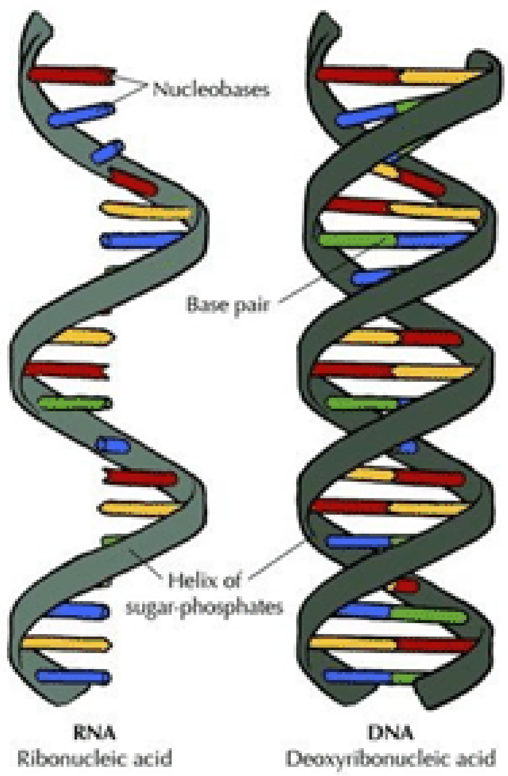
Proteins and Diet

Proteins in the diet are necessary for life. Dietary proteins are broken down into their smaller amino acids when food is digested. Cells can then use the amino acids to build new proteins. Humans are able to synthesize all but nine of the twenty common amino acids. These nine amino acids, called essential amino acids, must be consumed from

foods. Muscle tissues are composed of proteins; a good source of protein can be found in meat sources such as chicken, fish and beef.

Nucleic Acids

Nucleic acids (organic compounds that carry genetic information) contain carbon, hydrogen, oxygen, nitrogen, and phosphorus. They are made of smaller units called nucleotides. Nucleic acids are named for the nucleus of the cell, where some of them are found. Nucleic acids are found not only in all living cells but also in viruses. They are the building blocks of DNA and RNA.



Types of Nucleic Acids

- deoxyribonucleic acid (DNA)
- ribonucleic acid (RNA)

Functions of Nucleic Acids

Nucleic acids contain the information needed for cells to make proteins. This information is passed from a body cell to its daughter cells when the cell divides. It is also passed from parents to their offspring when organisms reproduce.

DNA and RNA have different functions relating to the genetic code and proteins. Like a set of blueprints, DNA contains the genetic instructions for the correct sequence of

amino acids in proteins. RNA uses the information in DNA to assemble the amino acids and make the proteins.

Lesson Summary

- Carbohydrates are the starches and sugars. They provide cells with quick energy.
- Lipids are the fats, oils and waxes. They provide cells with stored energy, and help form cell membranes.
- Proteins provide structure for cells and help speed up chemical reactions (enzymes).
- Nucleic acids contain genetic instructions for proteins, help synthesize proteins, and pass genetic instructions on to daughter cells and offspring.

Online Interactives-Simulations/Resources

Macromolecule Review

- http://go.uen.org/b2z

Think like a Biologist

1. State the function of carbohydrates, such as glucose and fructose.

2. Why are proteins important for you?

Water: Why do we really need it?

Objective

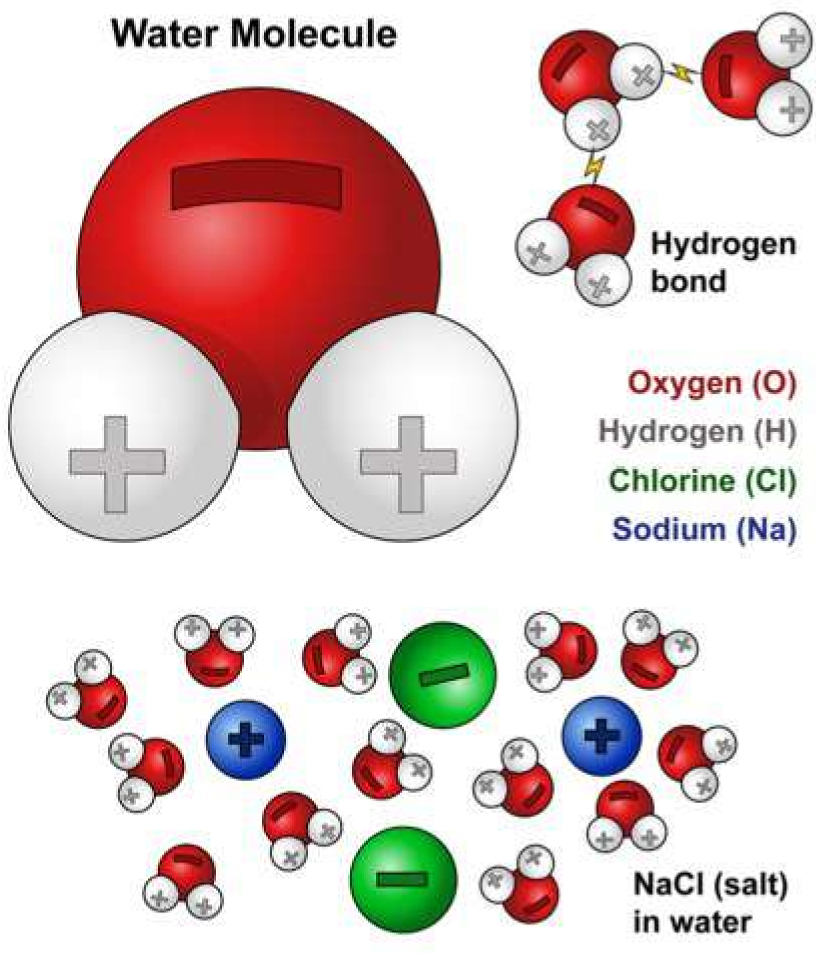
- Explain how the properties of water (e.g. cohesion, adhesion, heat capacity, solvent properties) contribute to maintenance of cells and living organisms.

Introduction

Water, like carbon, has a special role in biology because of its importance to organisms. The human body is approximately 50-75% water! Water is essential to all known forms of life. Approximately 75% of the surface of the earth is covered with water. Water (H2O) such a simple molecule, yet it is this simplicity that gives water its unique properties and explains why water is so vital for life.

Chemical Structure of Water

To understand some of water's properties, you need to know more about its chemical structure. As you see the image below, each molecule of water consists of one atom of oxygen and two atoms of hydrogen. The oxygen atom in a water molecule attracts electrons more strongly than the hydrogen atoms do. As a result, the oxygen atom has a slightly negative charge, and the hydrogen atoms have a slightly positive charge. A difference in electrical charge between different parts of the same molecule is called **polarity**.



*https://www.ck12.org/book/CK-12-Biology/section/2.3/

Properties of Water: What makes it so special?

Cohesion

Water has some unusual properties due to its hydrogen bonds. One property is the tendency for water molecules to stick together which is called cohesion. For example, if you drop a tiny amount of water onto a very smooth surface, the water molecules will stick together and form a droplet, rather than spread out over the surface. The same thing happens when water slowly drips from a leaky faucet.

Surface tension is when water molecules form an invisible layer which can hold weight. This phenomenon is due to cohesion. Water striders can glide across the surface of a pond due to the cohesion of the surface water molecules.

Droplets of dew cling to a spider web, demonstrating the tendency of water molecules to stick together because of hydrogen bonds.

Adhesion

Adhesion (when water molecules stick to other substances) is another property of water. This property of water can be observed when a paper towel is used to wipe up a pool of water. The water molecules stick to the molecules in the paper towel.

This sticking of water molecules to other molecules is also seen in nature when water is taken up by the roots in plants. This phenomenon is called capillary action.

Density

The melting point of water is 0°C. Below this temperature, water is a solid (ice). Unlike most chemical substances, water in a solid state has a lower density than water in a liquid state. This is because water expands when it freezes. Again, hydrogen bonding is the reason. Hydrogen bonds cause water molecules to line up with more space between each molecule in ice than in liquid water. As a result, water molecules are spaced farther apart in ice, giving ice a lower density than liquid water. A substance with lower density floats on a substance with higher density. Since ice floats in water, it acts as an insulator keeping the deeper water from freezing. This allows marine life to keep their habitat and live in the water.

Universal Solvent

The two parts of a solution are the solvent and the solute. The solute is the substance that dissolves in the solvent. Many chemical substances are soluble in water. In fact, so many substances are soluble in water that water is called the universal solvent. Water is a strongly polar solvent, and polar solvents are better at dissolving polar solutes. Many organic compounds and other important biochemicals are polar, so they dissolve well in water. On the other hand, strongly polar solvents like water cannot dissolve strongly nonpolar solutes like oil.

Heat Capacity

Water has a high heat capacity because it takes a lot of energy to raise or lower the temperature of water. As a result, water plays a very important role in temperature regulation. Since cells are made up of water, this property helps to maintain homeostasis.

Lesson Summary

- Water molecules are polar, so they form hydrogen bonds. This gives water unique properties, such as a relatively high boiling point.
- A solution is a which a solute dissolves in a solvent. Water is a very common solvent, especially in organisms.
- Water is essential for most life processes, including temperature regulation and other important chemical reactions that occur in organisms.

Think like a Chemist

1. Explain how hydrogen bonds cause molecules of liquid water to stick together.

2. Would the dew you see in the morning be an example of cohesion or adhesion? What is the difference between the two?

Enzymes and Chemical Reactions

Objective

- Explain the role of enzymes in cell chemistry.

Rates of Chemical Reactions

The rates at which chemical reactions take place in organisms are very important. Chemical reactions in organisms are involved in processes ranging from the contraction of muscles to the digestion of food. For example, when you wave goodbye, it requires repeated contractions of muscles in your arm over a period of a couple of seconds. A huge number of reactions must take place in that time, so each reaction cannot take longer than a few milliseconds. If the reactions took much longer, you might not finish waving until sometime next year.

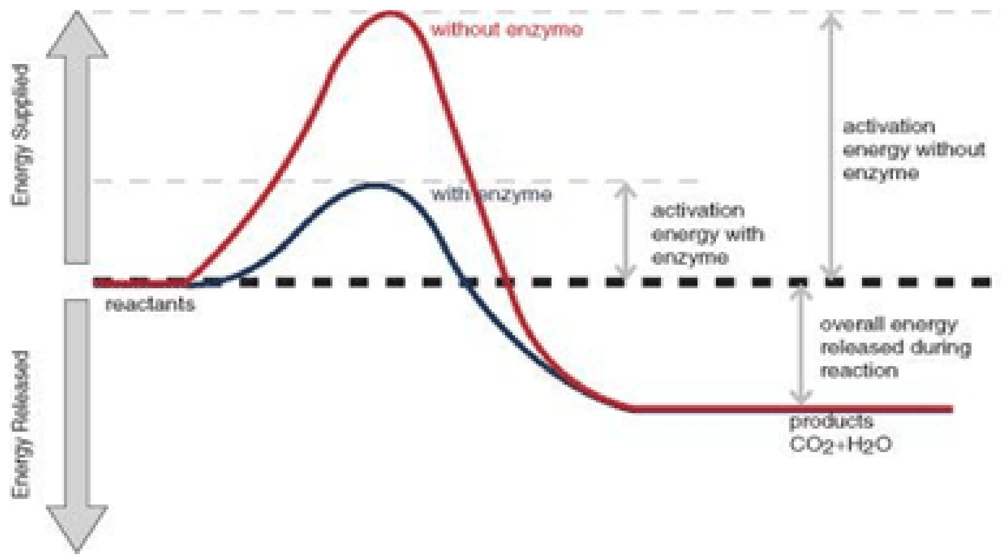
Enzymes and Biochemical Reactions

Most chemical reactions within organisms would be impossible under the conditions in cells. For example, the body temperature of most organisms is too low for reactions to occur quickly enough to carry out life processes. Therefore, the rate of most biochemical reactions must be increased by a catalyst. A catalyst is a chemical that speeds up chemical reactions. In organisms, protein catalysts are called enzymes. Enzymes make a reaction happen faster with less energy. They may be used over and over again. Unlike other catalysts, enzymes are usually highly specific for particular chemical reactions. They generally catalyze only one or a few types of reactions.

Enzymes are extremely efficient in speeding up reactions. They can catalyze up to several million reactions per second. As a result, the difference in rates of biochemical reactions with and without enzymes may be huge. A typical biochemical reaction might take hours or even days to occur under normal cellular conditions without an enzyme but less than a second with the enzyme.

How enzymes work

How do enzymes speed up biochemical reactions so much? Like all catalysts, enzymes work by lowering the activation energy of chemical reactions. See next figure.



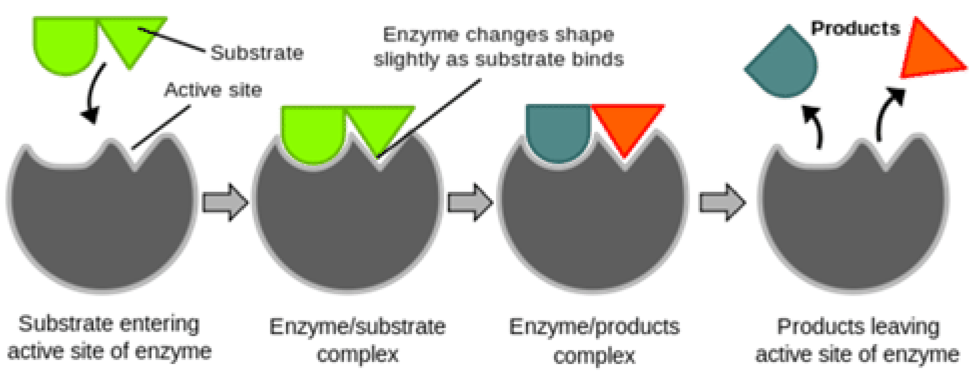
The reaction represented by this graph is a combustion reaction involving the reactants glucose ($C_6H_{12}O_6$) and oxygen (O_2). The enzyme speeds up the reaction by lowering the activation energy needed for the reaction to start. Compare the activation energy with and without the enzyme.

An animation of this process can be viewed at:

- http://go.uen.org/b2A

Enzymes generally lower activation energy by reducing the energy needed for reactants to come together and react. For example:

- Enzymes bring reactants together so they don't have to expend energy moving about until they collide at random. Enzymes bind both reactant molecules (called substrate), tightly and specifically, at a site on the enzyme molecule called the active site (Figure below).
- By binding reactants at the active site, enzymes also position reactants correctly. This allows the molecules to interact with less energy.
- Enzymes may also allow reactions to occur by different pathways that have lower activation energy.



This enzyme molecule binds reactant molecules called substrate at its active site, forming an enzyme-substrate complex. This brings the reactants together and positions

them correctly so the reaction can occur. After the reaction, the products are released from the enzyme's active site. This frees up the enzyme so it can catalyze additional reactions.

The activities of enzymes also depend on the temperature, ionic conditions, and the pH of the surroundings. Some enzymes work best at acidic pHs, while others work best in neutral environments.

Digestive enzymes secreted in the acidic environment (low pH) of the stomach help break down proteins into smaller molecules. The main digestive enzyme in the stomach is pepsin, which works best at a pH of about 1.5. These enzymes would not work optimally at other pHs. Trypsin is another enzyme in the digestive system that breaks protein chains in the food into smaller parts. Trypsin works in the small intestine, which is not an acidic environment. Trypsin's optimum pH is about 8.

Biochemical reactions are optimal at physiological temperatures. For example, most biochemical reactions work best at the normal body temperature of 98.6˚F. Many enzymes lose function at lower and higher temperatures. At higher temperatures, an enzyme's shape changes and only when the temperature comes back to normal does the enzyme regain its shape and normal activity. Some enzymes will permanently change if the conditions are too severe, like and egg going from a fluid-like substance to a solid when heated.

Importance of Enzymes

Enzymes are involved in most of the chemical reactions that take place in organisms. About 4,000 such reactions are catalyzed by enzymes, but the number may be even higher. Needed for reactions that regulate cells, enzymes allow movement, transport materials around the body, and movement of substances in and out of cells.

In animals, another important function of enzymes is to help digest food. Digestive enzymes speed up reactions that break down large molecules of carbohydrates, proteins, and fats into smaller molecules the body can use. Without digestive enzymes, animals would not be able to break down food molecules quickly enough to provide the energy and nutrients they need to survive.

Enzymes can be recognized by their name. Enzymes always end with the suffix -ase. Amylase is an enzyme in your mouth that breaks down carbohydrates. Lactase is an enzyme that breaks down lactose sugar in milk.

Summary

- A chemical reaction is a process that changes some chemical substances into others. It involves breaking and forming chemical bonds. Types of chemical reactions include synthesis reactions and decomposition reactions.
- Rates of chemical reactions depend on factors such as the concentration of reactants and the temperature at which reactions occur, and pH. These factors affect the ability of reactant molecules to react.

- Enzymes are needed to speed up chemical reactions in organisms. They work by lowering the activation energy of reactions and speeding up the reaction.

Online Interactives/Simulations

Animation on enzymes with quiz:

- http://go.uen.org/b2B

Interactive showing enzyme reactions and ATP/ADP cycle

- http://go.uen.org/b2C

Think like a Chemist

1. How do enzymes work to speed up chemical reactions?

2. What factors affect the reaction rate of enzymes or other catalysts?

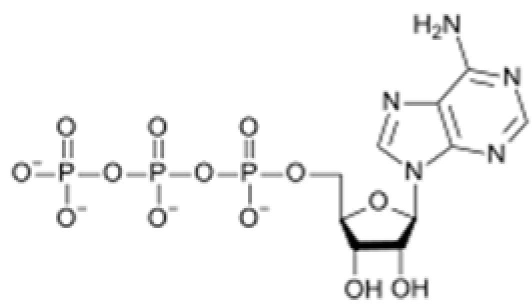
3. Why do all chemical reactions require activation energy?

4. Explain why organisms need enzymes to survive.

2.2 How Do Organisms Obtain Energy

Overview of ATP

Adenosine triphosphate (ATP) is the primary energy source for cells. ATP stores chemical energy in its bonds. This energy is used for cell metabolism and to maintain cell homeostasis.



A molecule of ATP

Summary

- Energy is the ability to do work.
- Organisms obtain light energy from sunlight or chemical energy from food and change the energy into different forms, including heat energy.
- ATP is the main energy of cells.

Autotroph vs. Heterotroph: How Organisms Obtain Energy

Objective

- Distinguish between autotrophic and heterotrophic cells.

Introduction

Different organisms get energy in different ways, but ultimately it all starts with sunlight. Plants absorb the energy from the sun and turn it into food. You can sit in the sun for hours and hours. You will feel warm, but you're not going to absorb any light energy. You have to eat to obtain your energy.

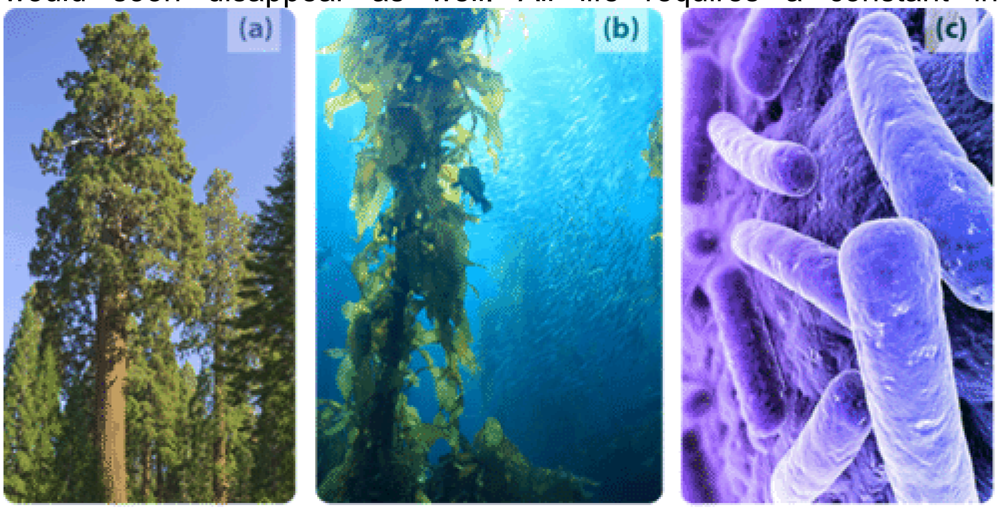
Autotrophs vs. Heterotrophs

Living organisms obtain chemical energy in one of two ways.

Autotrophs, also known as producers (See image below), store chemical energy in carbohydrate food molecules they build themselves. Food is chemical energy stored in organic molecules. Food provides both the energy to do work and the carbon to build bodies. Because most autotrophs transform sunlight to make food, we call the process they use photosynthesis. Autotrophs make food for their own use, but they make enough to support other life as well. Almost all other organisms depend absolutely on autotrophs for the food they produce. The producers are the beginning of food chains which feed all life.

Heterotrophs cannot make their own food so they must eat or absorb it. For this reason, heterotrophs are also known as consumers. Consumers include all animals, fungi, and many protists and bacteria. They may consume autotrophs or other heterotrophs or

organic molecules from other organisms. Heterotrophs show great diversity and may appear far more fascinating than producers, but heterotrophs are limited by their dependence on those autotrophs that originally made their own food. If plants, algae, and autotrophic bacteria vanished from earth, animals, fungi, and other heterotrophs would soon disappear as well. All life requires a constant input of energy.



Photosynthetic autotrophs, which make food using the energy in sunlight, include (a) plants, (b) algae, and (c) certain bacteria.

Summary

- Autotrophs store chemical energy in carbohydrate food molecules they build themselves. Most autotrophs make their “food” through photosynthesis using the energy of the sun.
- Heterotrophs cannot make their own food, so they must eat or absorb it.

Think like a Biologist

1. Compare an autotroph to a heterotroph. Give an example of each and describe the relationship between the two organisms and trace the flow of energy through an ecosystem.

Photosynthesis: How do plants make food?

Objectives

- Illustrate the cycling of matter and the flow of energy through photosynthesis and respiration.
- Measure the production of one or more products of either photosynthesis or respiration.

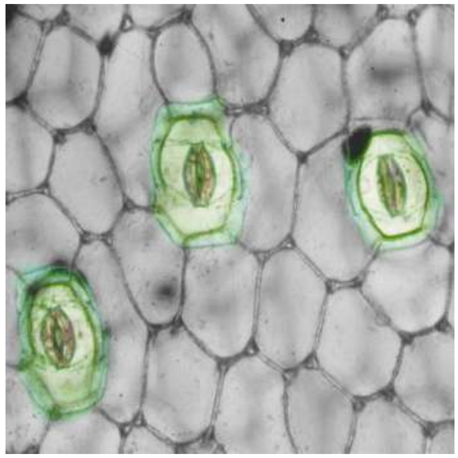
Introduction

Almost all life on Earth depends on photosynthesis. Recall that photosynthesis is the process by which plants use the sun's energy to make their own "food" from carbon dioxide and water. For example, animals, such as caterpillars, eat plants and therefore rely on the plants to obtain energy. If a bird eats a caterpillar, then the bird is obtaining the energy that the caterpillar gained from the plants. So the bird is indirectly getting energy that began with the "food" formed through photosynthesis. Almost all organisms obtain their energy from photosynthetic organisms, either directly, by eating photosynthetic organisms, or indirectly by eating other organisms that ultimately obtained their energy from photosynthetic organisms. Therefore, the process of photosynthesis is central to sustaining life on Earth.

Overview of Photosynthesis: Where does the energy come from?

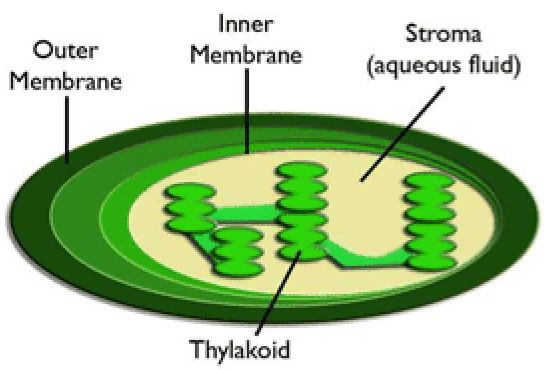
Photosynthesis is the process that converts the energy of the sun, or solar energy, into carbohydrates, a type of chemical energy. During photosynthesis, carbon dioxide and water combine with solar energy, yielding glucose (the carbohydrate) and oxygen. As mentioned previously, plants can photosynthesize, but plants are not the only organisms with this ability. Algae, which are plant-like protists, and cyanobacteria can also photosynthesize. Algae and cyanobacteria are important in aquatic environments as sources of food for larger organisms.

Photosynthesis mostly takes place in the leaves of a plant. The green pigment in leaves, chlorophyll, helps to capture solar energy. The veins within a leaf carry water which originates from the roots, and carbon dioxide enters the leaf from the air through special pores called stomata.



Stomata are special pores that allow gases to enter and exit the leaf.

The water and carbon dioxide are transported within the leaf to the chloroplast (next image), the organelle in which photosynthesis takes place. The chloroplast has two distinct membrane systems; an outer membrane surrounds the chloroplast and an inner membrane system forms flattened sacs called thylakoids. As a result, there are two separate spaces within the chloroplast. The interior space that surrounds the thylakoids is filled with a fluid called stroma. The inner compartments formed by the thylakoid membranes are called the thylakoid space.



The chloroplast is the photosynthesis factory of the plant.

The overall chemical reaction for photosynthesis is 6 molecules of carbon dioxide (CO_2) and 6 molecules of water (H_2O), with the addition of solar energy, yields 1 molecule of glucose ($C_6H_{12}O_6$) and 6 molecules of oxygen (O_2). Using chemical symbols the equation is represented as follows:

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} \xrightarrow{\text{Light}} \underset{\text{Sugar}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2}$$

Oxygen: An Essential Byproduct

Oxygen is a byproduct of the process of photosynthesis and is released to the atmosphere through the stomata. Therefore, plants and other photosynthetic organisms play an important ecological role in converting carbon dioxide into oxygen. Animals need oxygen to carry out the energy-producing reactions of their cells. Without photosynthetic organisms, many other organisms would not have enough oxygen in the atmosphere to survive. Oxygen is also used as a reactant in cellular respiration. Oxygen cycles through both processes of photosynthesis and cellular respiration.

Summary

- The net reaction for photosynthesis is that carbon dioxide and water, together with energy from the sun, produce glucose and oxygen.
- During the light reactions of photosynthesis, solar energy is converted into the chemical energy of ATP and NADPH, and releases oxygen.
- During the Calvin Cycle, the chemical energy of ATP and NADPH is used to convert carbon dioxide into glucose.
- Links for more understanding:
  - Photosynthesis crash course: http://go.uen.org/aYX
  - Photosynthesis song: http://go.uen.org/aYV

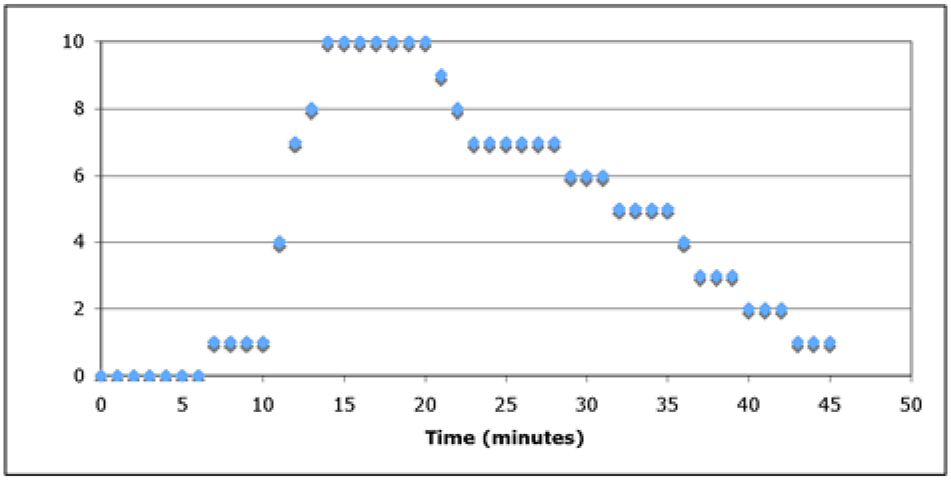
Online Interactives/Simulations

Virtual lab that measures the rate of photosynthesis. http://go.uen.org/aZ0

Virtual lab to test different colors of light and the effect on photosynthesis.
- http://go.uen.org/aZ4

Think like a Biochemist

1. Where does the oxygen released by photosynthesis come from?
2. What happens to the glucose produced from photosynthesis?
3. What are the reactants required for photosynthesis?
4. What are the products of photosynthesis?
5. An experiment was conducted where 10 leaf disks were created by cutting a small circle in a leaf then were placed in a sodium bicarbonate solution and placed in the light. Every minute, the number of floating disks were counted and recorded. After 14 minutes, the leaf disks were moved into the dark and the number of floating disks were recorded every minute. Below is a graphical representation of the data.



6. Why did the leaf disks begin to sink after being placed in the dark?

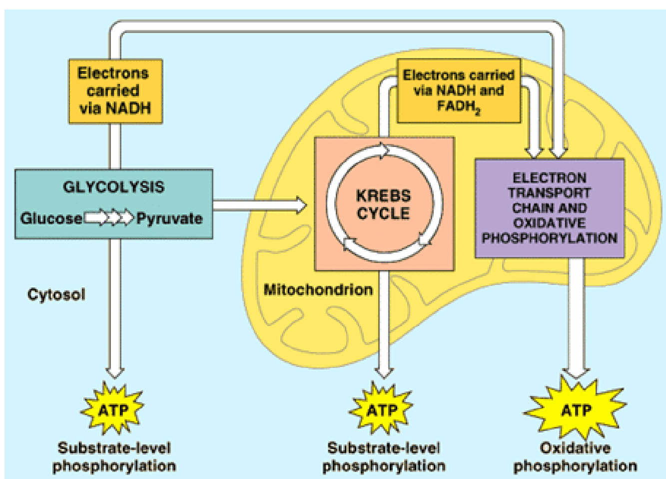
Cellular Respiration: How do your cells get energy?

Objectives

- Illustrate the cycling of matter and the flow of energy through photosynthesis and respiration.
- Measure the production of one or more products of either photosynthesis or respiration.

Introduction

How does the food you eat provide energy? When you need a quick boost of energy, you might reach for an apple or a candy bar. Although foods with sugars can give you a quick boost of energy, they cannot be used for energy directly by your cells. Energy is simply stored in these foods. Through the process of cellular respiration, the energy in food is changed into energy that can be used by the body's cells. In other words, glucose (and oxygen) is converted into ATP (and carbon dioxide and water). ATP is the molecule that provides energy for your cells to perform work, such as contracting your muscles as you walk down the street or performing active transport. Cellular respiration is simply a process that changes one type of chemical energy, the energy stored in sugar, into another type, ATP.



Overview of Cellular Respiration

Most often, cellular respiration proceeds by breaking down glucose into carbon dioxide and water. As this breakdown of glucose occurs, energy is released. The process of cellular respiration includes the conversion of this stored energy into ATP. The overall reaction for cellular respiration is as follows: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$.

Notice that the equation for cellular respiration is the direct opposite of photosynthesis. While water was broken down to free hydrogen and oxygen during photosynthesis, in cellular respiration oxygen is combined with hydrogen to form water. While

photosynthesis requires carbon dioxide and releases oxygen, cellular respiration requires oxygen and releases carbon dioxide. This cycle of carbon dioxide and oxygen in all the organisms that use photosynthesis and/or cellular respiration worldwide, helps to balance atmospheric oxygen and carbon dioxide.

Summary

- Cellular respiration is the breakdown of glucose to release energy in the form of ATP.

Online Interactives/Simulations

Photosynthesis and cellular respiration labeling interactive.

- http://go.uen.org/aZp

In depth animation explaining steps of cellular respiration. http://go.uen.org/aZs

Interactive on photosynthesis and cellular respiration with the ability to click on structure to identify function and role in photosynthesis and respiration.

- http://go.uen.org/aZt

Think like a Biochemist

1. Write the chemical reaction for the overall process of cellular respiration.

2.3 Introduction to Cells

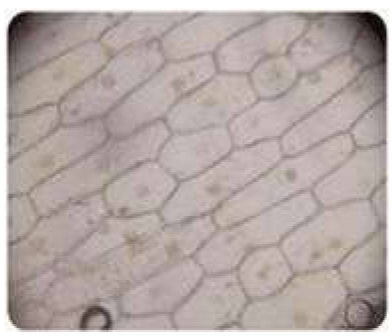
How were cells discovered?

Objective

- Describe the Cell Theory and relate the nature of science to the development of the Cell Theory.

Introduction

How do fats/lipids, carbohydrates, proteins, and nucleic acids come together to form a living organism? By forming a cell. These organic compounds are the raw materials needed for life, and a cell is the smallest unit of an organism that is still considered living. Cells are the basic units that make up every type of organism. Some organisms, like bacteria, consist of only one cell. Other organisms, like humans, consist of trillions of specialized cells working together. Even if organisms look very different from each other, if you look close enough you'll see that their cells have much in common. (image below)).



The outline of onion cells are visible under a light microscope.

Observing Cells: How do we see cells?

Most cells are so tiny that you can't see them without the help of a microscope. The microscopes that students typically use at school are light microscopes. Robert Hooke created a primitive light microscope in 1665 and observed cells for the very first time. Although the light microscope opened our eyes to the existence of cells, they are not useful for looking at the tiniest components of cells. Many structures in the cell are too small to see with a light microscope.

When scientists developed more powerful microscopes in the 1950s, the field of cell biology grew rapidly. A light microscope passes a light beam through a specimen, but

the more powerful electron microscope passes a beam of electrons through the specimen, allowing a much closer look at the cell (next image).

An electron microscope allows scientists to see much more detail than a light microscope, as with this sample of pollen. But a light microscope allows scientists to study living cells.

Transmission electron microscopes (TEM), which pass an electron beam through something, are used to look at a very thin section of an organism and allow us to study the internal structure of cells. Scanning electron microscopes (SEM), which pass a beam of electrons across the surface of something, show the details of the shapes of surfaces, giving a 3D image.

Electron microscopes showed many small structures in the cell that had been previously invisible with light microscopes. One drawback to using an electron microscope is that it only images dead cells. A light microscope can be used to study living cells.

Cell Theory

In 1858, after microscopes had become much more sophisticated than Hooke's first microscope, Rudolf Virchow proposed that cells only came from other cells. For example, bacteria are composed of only one cell and divide in half to replicate themselves. In the same way, your body makes new cells by the division of cells you already have. In all cases, cells only come from pre-existing cells.

This concept is central to the cell theory. The cell theory states that:

- All organisms are made of cells.
- Cells are alive and the basic living units of all organisms.
- New cells come from other cells.

Credit for developing cell theory is usually given to three scientists: Theodor Schwann, who stated all animals are made of cells, Matthias Jakob Schleiden who stated all plants are made of cells, and Rudolf Virchow who observed cells dividing. In 1839, Schwann and Schleiden suggested that cells were the basic unit of life. Their theory accepted the first two tenets of modern cell theory. In 1855, Rudolf Virchow concluded that all cells come from pre-existing cells. Since 1855 when Virchow introduced the ideas, the cell theory has been supported by thousands of experiments and no evidence has ever contradicted it.

Summary

- Cells were first observed under the light microscope, but today electron microscopes allow scientists to take a closer look at the internal structures of cells.

- The Cell Theory says that
- All organisms are composed of cells;
- Cells are alive and the basic living units of organization in all organisms; and
- New cells come from other cells.

Think like a Cell Biologist

1. What are the three parts of the cell theory?

2. Which scientist first discovered cells?

3. Keeping cell theory in mind, can we create a cell in the laboratory from organic molecules?

4. Do you think a bacteria cell and brain cell have some things in common? What might they be?

Cell Structure: What are Cells Made of?

Objective

- Describe the relationship between the organelles in a cell and the functions of that cell.

Introduction

Understanding the structure and function of cells is essential to understanding how living organisms work. Cell biology is central to all other fields of biology, including medicine. Many human diseases and disorders are caused by the malfunction of people's cells. Toxins in the environment often impact specific cellular processes. The healthy functioning of the body and its organs is dependent on its smallest unit - the cell. To better understand the biology of the cell, you will first learn to distinguish the two basic categories of all cells: prokaryotic and eukaryotic cells. You will also learn what makes a cell specialized; there are major differences between a "simple" cell, like bacteria, and a "complex" cell, like a cell in your brain.

To understand these differences, you need to first understand the basic components of the cell, which include the:

- Cell membrane
- Nucleus and chromosomes
- Other organelles

The Plasma Membrane and Cytosol

Both eukaryotic and prokaryotic cells have a plasma membrane. The plasma membrane is a double layer of specialized lipids, known as phospholipids, along with many special proteins. The function of the plasma membrane, also known as the "cell membrane", is to control what goes in and out of the cell.

Some molecules can go through the cell membrane while some can't. Biologists call that membrane semipermeable. It is almost as if the membrane chooses what enters and leaves the cell.

The cell membrane gives the cell an inside that is separate from the outside world. Without a cell membrane, the parts of a cell would just float away. Without a cell membrane, a cell would be unable to maintain a stable internal environment separate from the external environment, what we call homeostasis.

Eukaryotic and prokaryotic cells also share an internal fluid-like substance called the cytoplasm. The cytoplasm is composed of water and other molecules, including enzymes that speed up the cell's chemical reactions

ORGANELLE	FUNCTION
Ribosomes	Involved in making proteins
Golgi apparatus	Packages proteins and some polysaccharides
Mitochondria	Makes ATP (energy)
Smooth Endoplasmic Reticulum	Makes lipids, transports
Rough Endoplasmic Reticulum	Makes proteins, transports
*Chloroplast	Makes sugar (photosynthesis)
Lysosomes	Digests macromolecules
*Cell Wall	Support, structure
Cell Membrane	Regulates input & output; semipermeable
Vacuole	Storage of water, nutrients and wastes
Cytoplasm	Fluid that contains organelles
Nucleus	Controls functions of the cell, contains DNA
Nucleolus	Where ribosomes are made
^Centriole	Aids in cell division

*indicates structures specific to plant cells.

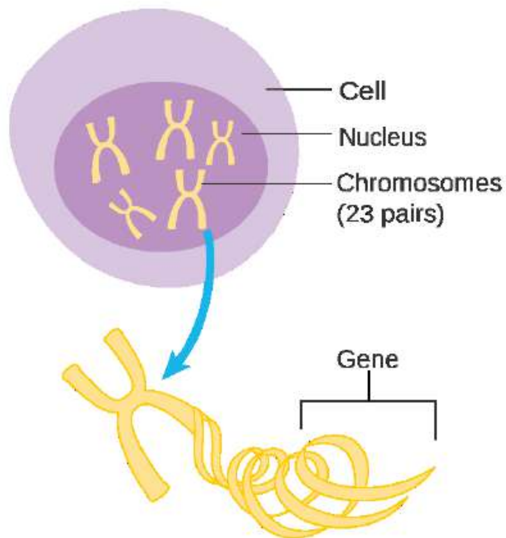
^indicates structures specific to animal cells.

The Nucleus and Chromosomes

The nucleus, which is found exclusively in eukaryotic cells, is a membrane-enclosed structure that contains most of the genetic material of the cell (image below). Like a

library, it holds vital information, mainly detailed instructions for building proteins. The nuclear envelope, a double membrane that surrounds the nucleus, controls which molecules go in and out of the nucleus.

Inside the nucleus are the chromosomes, the DNA are all wrapped in special proteins. The genetic information on the chromosomes is stored, made it available to the cell when necessary, and also duplicated when it is time to pass the genetic information on when a cell divides. All the cells of a species carry the same number of chromosomes. For example, human cells each have 23 pairs of chromosomes. Each chromosome in turn carries hundreds or thousands of genes that encode proteins that help determine traits as varied as tooth shape, hair color, or kidney function.



The Cell Factory

Just as a factory is made up of many people, machines, and specific areas, each part of the whole playing a different role, a cell is also made up of different parts, each with a special role. For example, the nucleus of a cell is like a safe containing the factory's trade secrets, including how to build thousands of proteins, how much of each one to make, and when.

The mitochondria are powerhouses that generate the cellular energy, called ATP, needed to power chemical reactions. Plant cells have special organelles called chloroplasts that capture energy from the sun and store it in the chemical bonds of sugar molecules - in the process called photosynthesis. The cells of animals and fungi do not photosynthesize and do not have chloroplasts.

The vacuoles are storage centers, and the lysosomes are the recycling trucks that carry waste away from the factory. Inside lysosomes are enzymes that break down old molecules into parts that can be recycled into new ones. Eukaryotic cells also contain an internal skeleton called the cytoskeleton. Like our bony skeleton, a cell's cytoskeleton gives the cell a shape and helps it move parts of the cell.

In both eukaryotes and prokaryotes, ribosomes are where proteins are made. Some ribosomes cluster on folded membranes called the endoplasmic reticulum (ER). If the

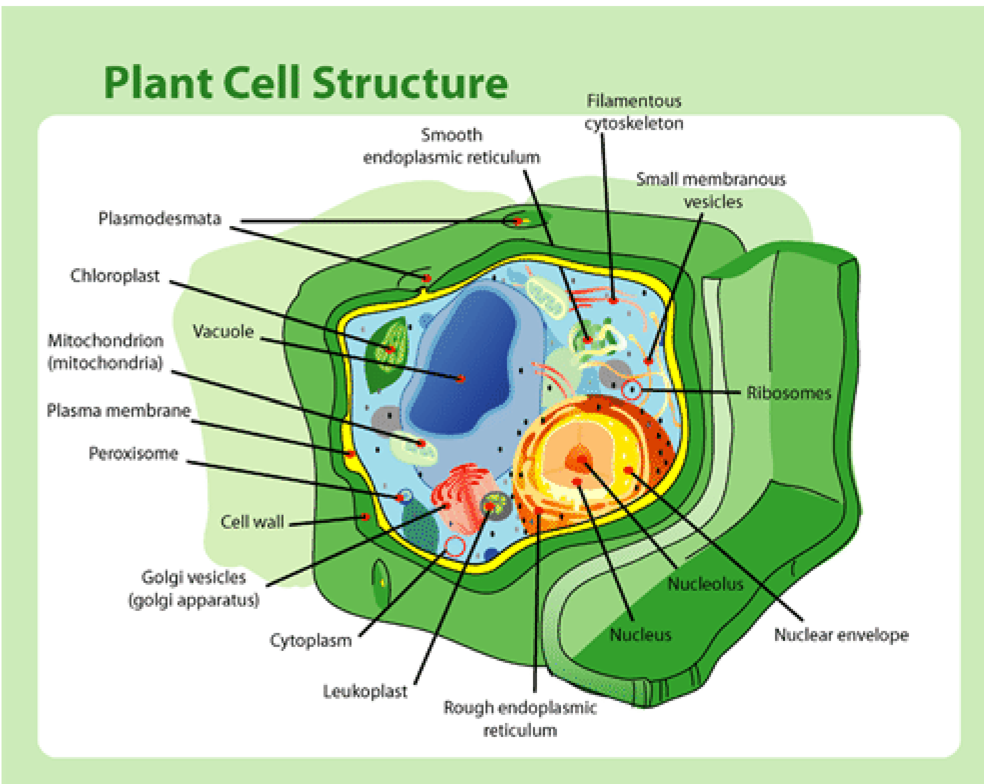
ER is covered with ribosomes, it looks bumpy and is called rough ER. If the ER lacks ribosomes, it is smooth and is called smooth ER. Proteins are made on rough ER and lipids are made on smooth ER.

Another set of folded membranes in cells is the Golgi apparatus, which works like a mailroom. The Golgi apparatus receives the proteins from the rough ER, packages them up in vesicles, and then sends them to the right place in the cell.

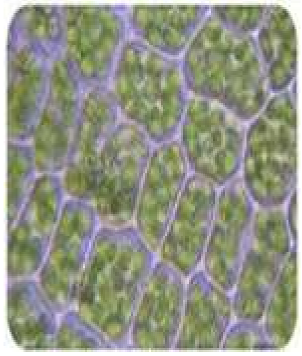
Plant Cells

Plant cells differ in some ways from animal cells. First, plant cells are unique in having a large central vacuole that holds a mixture of water, nutrients, and wastes. A plant cell's vacuole can make up 90% of the cell's volume. In animal cells, vacuoles are much smaller.

Second, plant cells have a cell wall, which animal cells do not. A cell wall gives the plant cell strength, rigidity, and protection. Although bacteria and fungi also have cell walls, a plant cell wall is made of a different material.



A plant cell has several features that make it different from an animal cell, including a cell wall, huge vacuoles, and chloroplasts which carry out photosynthesis.



In this photo of plant cells taken with a light microscope, you can see a cell wall (purple) around each cell and green chloroplasts.

Summary

- Each component of a cell has a specific function.
- Plant cells have unique features including cell walls, and central vacuoles.

Online Interactives/Simulations

Interactive Cell Models:
- http://go.uen.org/aZK

Interactive Cell Structure, information on recognizing differences between prokaryotic and eukaryotic cells, plant and animal cells, and the function of cell structures:
- http://go.uen.org/aZL

Think like a Cell Biologist

1. What are organelles?
2. What is the plasma membrane and what is its role?
3. What organelle is known as the "powerhouse" of the cell?
4. What are the some differences between a plant cell and an animal cell?

Points to Consider

- Think about what molecules would need to be transported into cells.
- Discuss why it would be important for some molecules to be kept out of a cell.

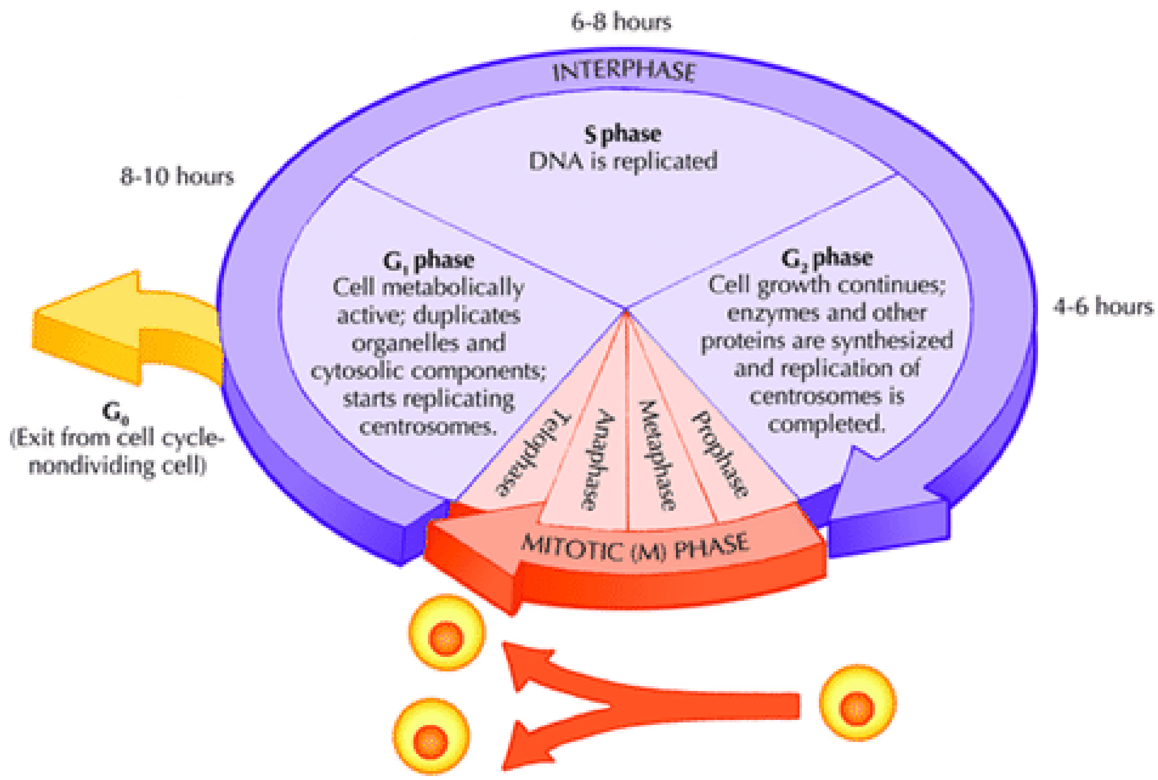
The Cell Cycle: How Do You Grow?

Objective

- Explain how cells divide from existing cells.

The Cell Cycle

The cell cycle is the series of events that takes place in a cell that results in DNA replication and cell division. There are two main stages in the cell cycle. The first stage is interphase during which the cell grows and replicates its DNA. The second phase is the mitotic phase (M-Phase) during which the cell divides and transfers one copy of its DNA to two identical daughter cells.



Interphase is the longest phase of the cell cycle. During this phase the cell grows to its maximum size, performs its normal cellular functions, replicates its DNA, and prepares for cell division. This stage is divided into three parts: G1, G2, and S phases.

Mitotic Phase

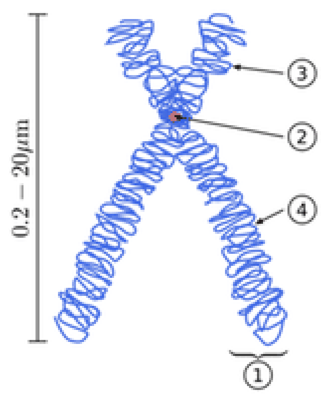
The mitotic phase (M phase) is composed of two tightly coupled processes: mitosis and cytokinesis. During mitosis the chromosomes in the cell nucleus separate into two identical sets in two nuclei. This is followed by cytokinesis in which the cytoplasm, organelles and cell membrane split into two cells containing roughly equal shares of

these cellular components. We will now describe what takes place during the stages of M-phase, which includes the four broad phases of mitosis (prophase, metaphase, anaphase, telophase) and the fifth phase of cytokinesis:

- prophase
- metaphase
- anaphase
- telophase
- cytokinesis

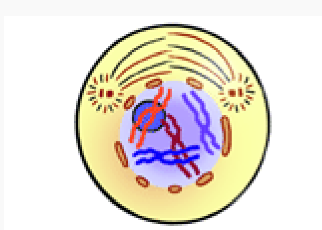
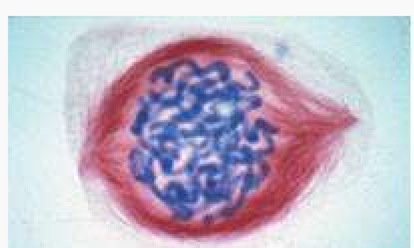
1. Prophase

During prophase, the chromatin material shortens and thickens into individual chromosomes which are visible under the light microscope. Each chromosome consist of two strands or chromatids joined by a centromere.



Chromosome structure showing (1) Chromatid, (2) Centromere, (3) Short and (4) Long arms of chromosome.

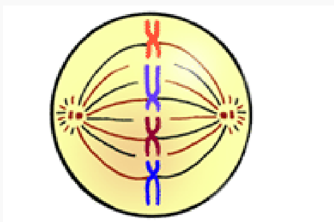
As prophase progresses, the nuclear membrane and nucleolus disintegrates. In animal cells the centrioles separate and move to opposite poles. The centrioles give rise to the spindle fibers which form between the poles. In plant cells there are no centrioles to move to the poles, so spindle fibers form in the cytoplasm.

Schematic Diagram: animal cell	Micrograph: animal cell
	

2. Metaphase

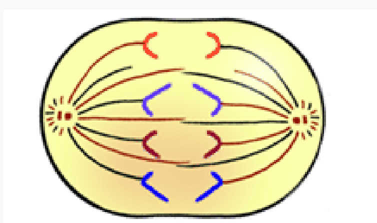
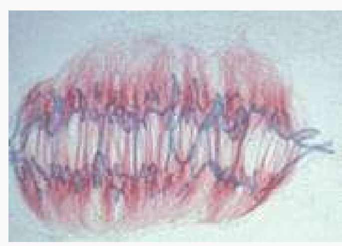
During metaphase, chromosomes line up on the equator of the cell. The chromosomes appear in a straight line across the middle of the cell. Each chromosome is attached to the spindle fibres by its centromere.

The stages of the cell cycle (interphase, prophase, metaphase, anaphase, telophase) can be remembered by using the mnemonic IPMAT.

Schematic Diagram: animal cell	Micrograph: animal cell
	

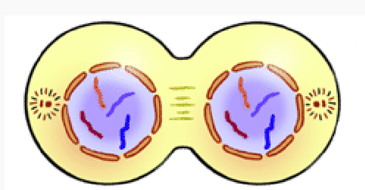
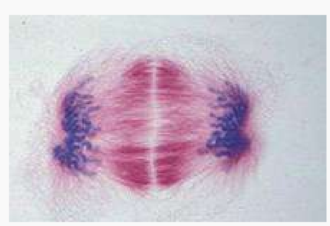
3. Anaphase

During anaphase the chromatids are pulled to opposite poles of the cell by the shortening of the spindle fibers. The chromatids are now called daughter chromosomes.

Schematic Diagram: animal cell	Micrograph: animal cell
	

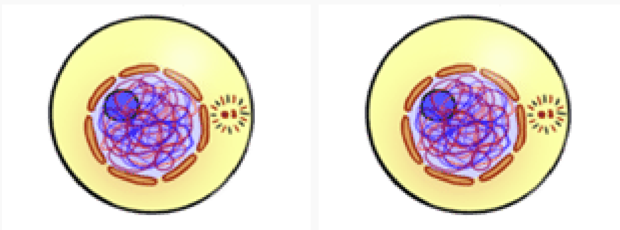
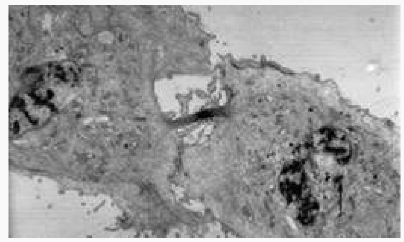
4. **Telophase**

During telophase, a nuclear membrane reforms around the daughter chromosomes that have gathered at each of the poles. The daughter chromosomes uncoil to form chromatin once again. The nuclear membrane reforms.

Schematic Diagram: animal cell	Micrograph: plant cell
	

5. Cytokinesis

The cytoplasm then divides during a process called cytokinesis. Cytokinesis is not a stage of mitosis but the process of the cytoplasm splitting into two. In an animal cell the cell membrane constricts. This folding of the cytoplasm divides the cell in two. In a plant cell a cross wall is formed by the cell plate dividing the cytoplasm in two.

Schematic Diagram: animal cell	Micrograph: animal cell
	

There are now two genetically identical daughter cells which are identical to the parent cell and to each other.

Transport: How do materials get into and out of a cell?

Objective

- Describe how the transport of materials in and out of cells enables cells to maintain homeostasis (i.e. Osmosis, diffusion, active transport).

Introduction

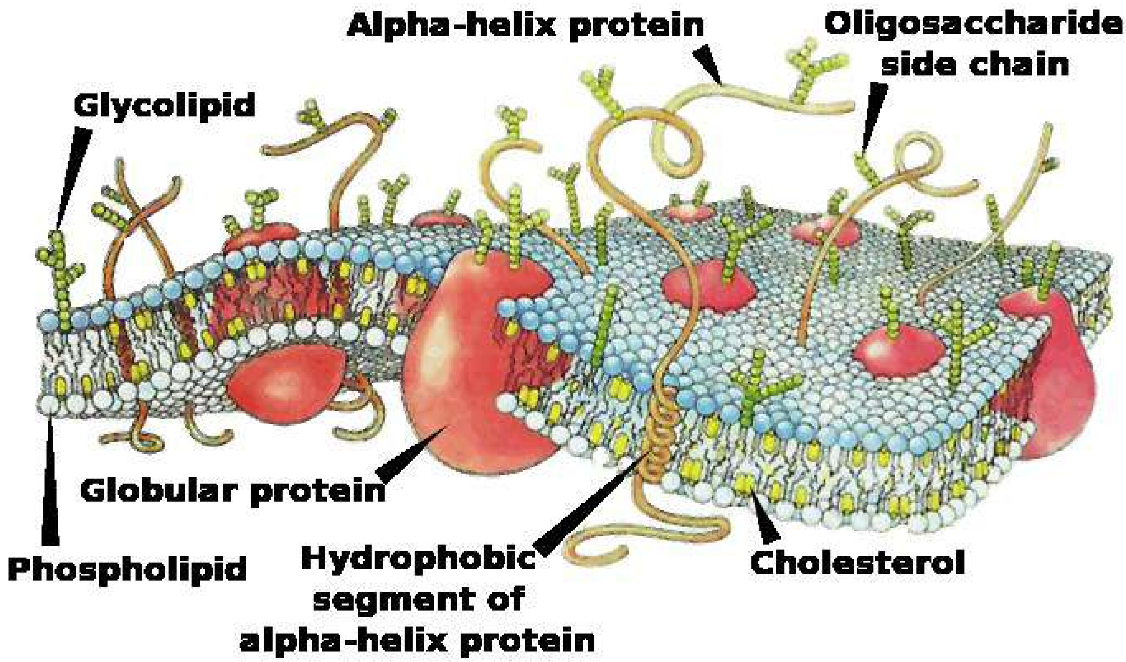
All organisms and their cells need to maintain homeostasis. But how can a cell keep a stable internal environment when the environment around the cell is constantly changing? Obviously, the cell needs to separate itself from the external environment. This job is accomplished by the cell membrane. The cell membrane is selectively permeable, or "semipermeable", which means that only some molecules can get through the membrane. If the cell membrane was completely permeable, the inside of the cell would be about the same as the outside and the cell could not achieve homeostasis.

How does the cell maintain this selective permeability? How does the cell control what molecules enter and leave the cell? The ways that cells control what passes through the cell membrane will be the focus of this lesson.

What is Transport?

The selectively permeable nature of the plasma membrane is due in part to the chemical composition of the membrane. Recall that the membrane is a double layer of phospholipids (a "bilayer") embedded with proteins (next image). A single phospholipid molecule has a hydrophilic, or water-loving, head and hydrophobic, or water-fearing, tail. The hydrophilic heads face the inside and outside of the cell, where water is abundant. The water-fearing, hydrophobic tails face each other in the middle of the membrane. At body temperature, the plasma membrane is fluid and constantly moving, like the surface of a soap bubble; it is not a solid structure.

Water and small non-charged molecules such as oxygen and carbon dioxide can pass freely through the membrane by slipping around the phospholipids. But larger molecules and charged molecules cannot pass through the plasma membrane easily. Therefore, special methods are needed for transporting some molecules across the plasma membrane and into or out of the cell. The plasma membrane is made up of a phospholipid bilayer with embedded proteins.



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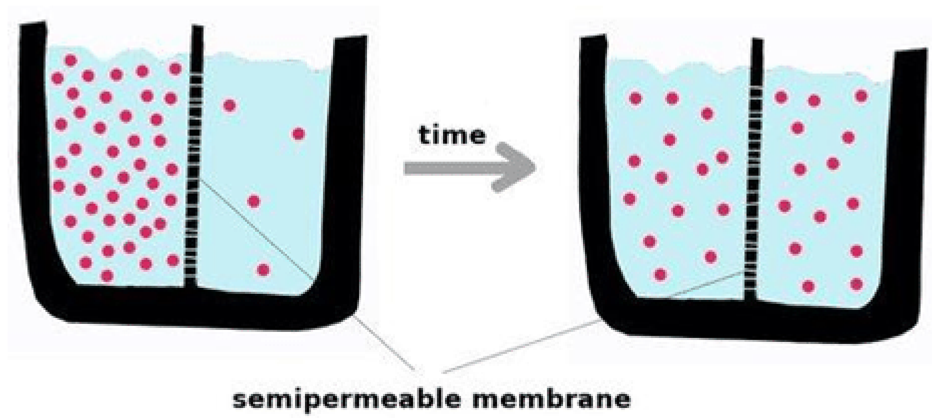
Passive Transport

Small molecules can pass through the plasma membrane through a process called diffusion. Diffusion is the movement of molecules from an area where there is a higher concentration (larger amount) of the substance to an area where there is a lower concentration (lower amount) of the substance. The amount of a substance in relation to the volume, is called concentration. Diffusion requires no energy input from the cell (next image). Diffusion occurs by the random movement of molecules; molecules move in both directions (into and out of the cell), but there is a greater movement from an area of higher concentration towards an area of lower concentration. The movement of the substance from a greater concentration to a lesser concentration is referred to as moving down the concentration gradient. For example, oxygen diffuses out of the air sacs in your lungs into your bloodstream because oxygen is more concentrated in your lungs than in your blood. Oxygen moves down the concentration gradient from your lungs into your bloodstream.

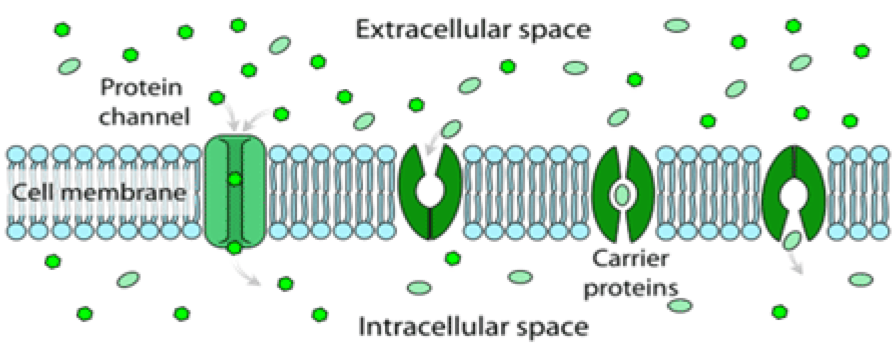


Diffusion across a membrane does not require an input of energy.

The diffusion of water across a membrane due to concentration differences is called osmosis. If a cell is placed in a hypotonic solution, meaning the solution has a lower concentration of dissolved material than what is inside the cell, water will move into the cell. This causes the cell to swell, and it may even burst. Organisms that live in freshwater, which is a hypotonic solution, have to prevent too much water from coming into their cells. Freshwater fish excrete a large volume of dilute urine to rid their bodies of excess water.

Sometimes diffusion across the membrane is slow or even impossible for some charged or large molecules. These molecules need the help of special helper proteins that are located in the plasma membrane. Ion channel proteins move ions across the plasma membrane. Other molecules, such as glucose, move across the cell membrane by facilitated diffusion, in which a carrier protein physically moves the molecule across the membrane (See figure). Both channel proteins and carrier proteins are specific for the molecule transported. Movement by ion channel proteins and facilitated diffusion are still considered passive transport, meaning they move molecules down the cell's concentration gradient and do not require any energy input.

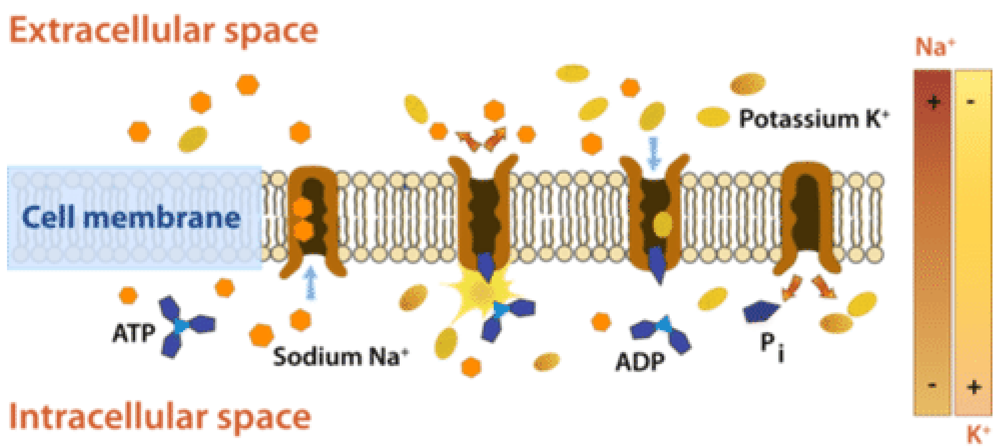
Facilitated Diffusion is a type of passive transport where a carrier protein aids in moving the molecule across the membrane.



Active Transport

During active transport, molecules move against the concentration gradient, toward the area of higher concentration. This is the opposite of diffusion. Active transport requires both an input of energy, in the form of ATP, and a carrier protein to move the molecules. These proteins are often called pumps, because, as a water pump uses energy to force water against gravity, proteins involved in active transport use energy to move molecules against their concentration gradient.

There are many examples of why active transport is important in your cells. One example occurs in your nerve cells. In these cells, the sodium-potassium pump (next image) moves sodium out of the cell and potassium into the cell, both against their concentration gradients.



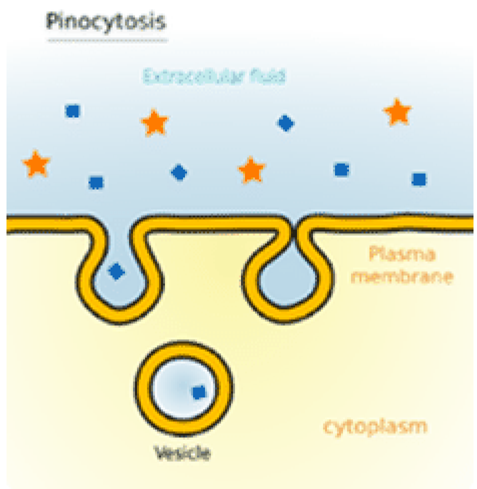
The sodium-potassium pump moves sodium ions to the outside of the cell and potassium ions to the inside of the cell. ATP is required for the protein to change shape. As ATP adds a phosphate group to the protein, it leaves behind adenosine diphosphate (ADP).

Transport through Vesicles

Some large molecules are just too big to move across the membrane, even with the help of a carrier protein. These large molecules must be moved through vesicle formation, a process by which the large molecules are packaged in a small bubble of membrane for transport. This process keeps the large molecules from reacting with the cytoplasm of the cell. Vesicle formation does require an input of energy, however.

There are several kinds of vesicle formation that allow large molecules to move across the plasma membrane. Exocytosis moves large molecules outside of the cell. During exocytosis, the vesicle carrying the large molecule fuses with the plasma membrane. The large molecule is then released outside of the cell, and the vesicle is absorbed into the plasma membrane. Endocytosis is the process by which cells take in large molecules by vesicle formation. Types of endocytosis include phagocytosis and pinocytosis.

Phagocytosis moves large substances, even another cell, into the cell. Phagocytosis occurs frequently in single-celled organisms, such as amoebas. Pinocytosis (See figure) involves the movement of liquid or very small particles into the cell. These processes cause some membrane material to be lost as these vesicles bud off and come into the cell. This membrane is replaced by the membrane gained through exocytosis.



During endocytosis, exocytosis and pinocytosis, substances are moved into or out of the cell via vesicle formation.

Summary

- The plasma membrane is selectively permeable or semipermeable, meaning that some molecules can move through the membrane easily, while others require specialized transport mechanisms.
- Passive transport methods, including diffusion, ion channels, facilitated diffusion, and osmosis, move molecules in the direction of the lowest concentration of the molecule and do not require energy.
- Active transport methods move molecules in the direction of the higher concentration and require energy and a carrier protein.
- Vesicles can be used to move large molecules, which requires energy input.

Online Interactives/Simulations

Part one of an interactive game to understand meiosis and fertilization and passing on of genetic characteristics:

- http://go.uen.org/aZO

Cells Alive Interactive Mitosis:

- http://go.uen.org/aZR
-

Think like a Cell Biologist

1. What's the main difference between active and passive transport?

2. List an example of active transport.

3. List the types of passive transport.

4. Why is the plasma membrane considered semipermeable?

5. What is the process where a cell engulfs a macromolecule, forming a vesicle?

6. What is diffusion?

7. Explain the results of a sodium-potassium pump working across a membrane.

8. Does facilitated transport move a substance down or up a gradient?

CHAPTER 3

Standard III: Organs and Organ Systems

Chapter Outline

Standard 3: Students will understand the relationship between structure and function of organs and organ systems.

Objective 1: Describe the structure and function of organs.

a. Diagram and label the structure of the primary components of representative organs in plants and animals (e.g., heart - muscle tissue, valves and chambers; lung - trachea, bronchial, alveoli; leaf - veins, stomata; stem - xylem, phloem, cambium; root - tip, elongation, hairs; skin - layers, sweat glands, oil glands, hair follicles; ovaries - ova, follicles, corpus luteum).

b. Describe the function of various organs (e.g. heart, lungs, skin, leaf, stem, root, ovary).

c. Relate the structure of organs to the function of organs.

d. Compare the structure and function of organs in one organism to the structure and function of organs in another organism.

e. Research and report on technological developments related to organs.

Objective 2: Describe the relationship between structure and function of organ systems in plants and animals.

a. Relate the function of an organ to the function of an organ system.

b. Describe the structure and function of various organ systems (i.e., digestion, respiration, circulation, protection and support, nervous) and how these systems contribute to homeostasis of the organism.

c. Examine the relationships of organ systems within an organism (e.g., respiration to circulation, leaves to roots) and describe the relationship of structure to function in the relationship.

d. Relate the tissues that make up organs to the structure and function of the organ.

e. Compare the structure and function of organ systems in one organism to the structure and function in another organism (e.g., chicken to sheep digestive system; fern to peach reproductive system).

Unit Key Vocabulary

- Organ
- Organ System
- Organism
- Hormonal Modification
- Stomata
- Tissue
- Homeostasis
- Structure
- Function

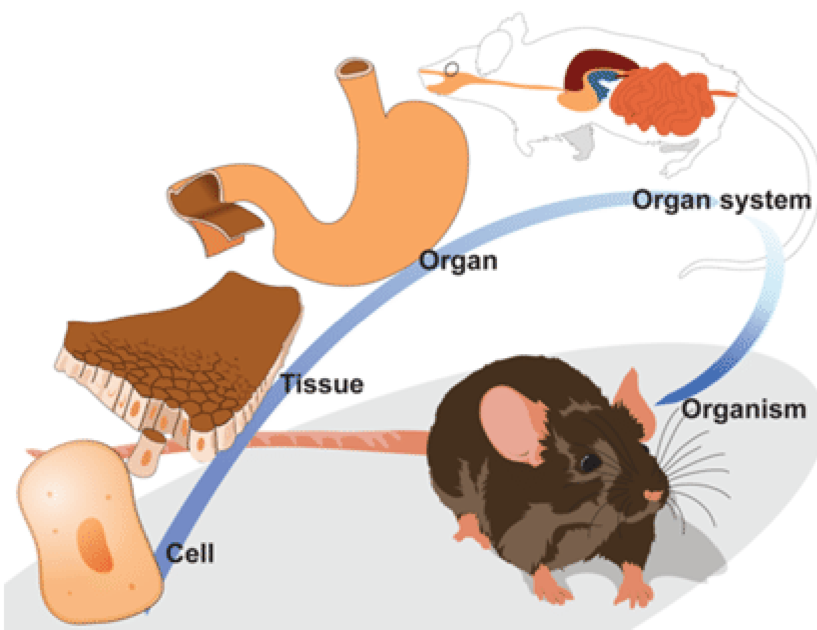
3.1 Organization of Living Things

Parts of a Machine: How does the body work?

Many people have compared the human body to a machine. Think about some common machines, such as drills and washing machines. Each machine consists of many parts, and each part does a specific job, yet all the parts work together to perform an overall function. The human body is like a machine in all these ways. Each organ functions and supports the body in a specific way that helps the whole organism.

Levels of Organization

All multicellular organisms are organized at different levels, starting with the cell and ending with the entire organism (See figure). At each higher level of organization, there is a greater degree of complexity.



An individual mouse is made up of several organ systems. The system shown here is the digestive system, which breaks down food into a form that cells can use. One of the organs of the digestive system is the stomach. The stomach, in turn, consists of different types of tissues. Each type of tissue is made up of cells of the same type.

Cells, Tissues, and Organs, Oh My!

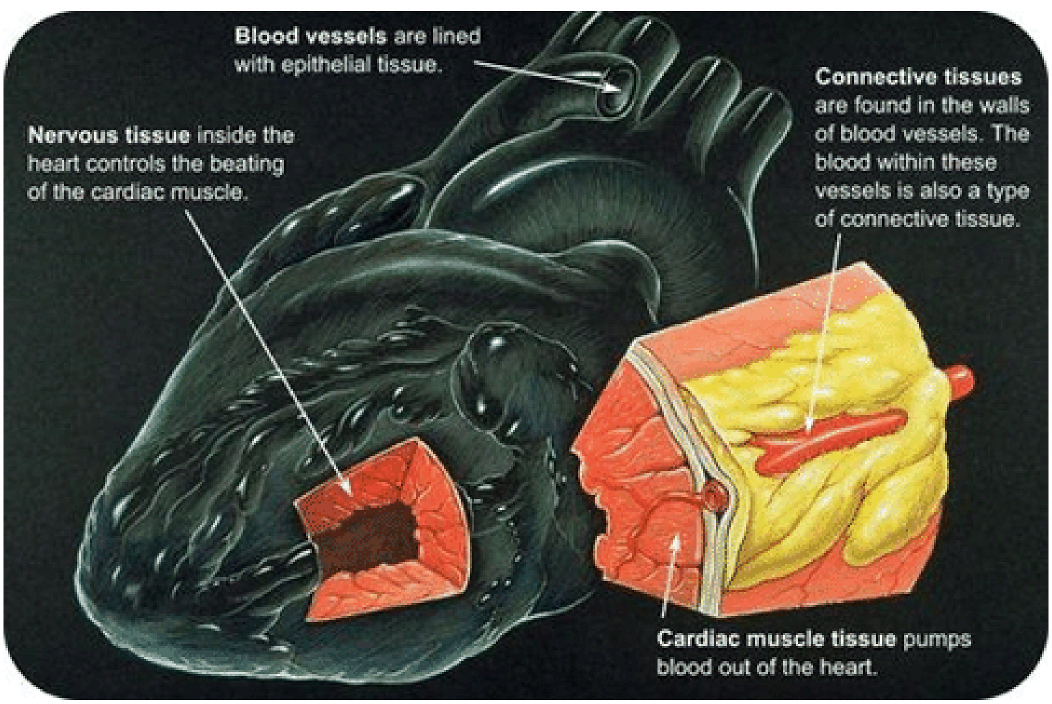
Cells are grouped together to carry out specific functions. A tissue is a group of cells that work together. Your body has four main types of tissues, as do the bodies of other animals. These tissues make up all structures and contents of your body. (See figure)

Groups of Tissues Form Organs

A single tissue alone cannot do all the jobs that are needed to keep an organism alive and healthy. After tissues, organs (a structure that consists of two or more types of tissues that work together to do the same job) are the next level of organization of the human body. The heart, (See figure), is made up of the four types of tissues.

The four different tissue types work together in the heart as they do in the other organs.

Examples of human organs include the brain, heart, lungs, skin, and kidneys. Human organs are organized into organ systems (a group of organs that work together to carry out a complex overall function). For instance, the heart, blood, and blood vessels form the cardiovascular system. (See Figure)



You can watch overviews of the human organ systems and their functions (See links).

- http://go.uen.org/b1x http://go.uen.org/b1z http://go.uen.org/b1A

A Well-Oiled Machine

All of the organs and organ systems of the human body work together like a well-oiled machine to make an organism (a living thing made of organ systems). This is because they are closely regulated by the nervous and endocrine systems. The nervous system controls virtually all body activities, and the endocrine system secretes hormones that regulate these activities. Functioning together, the organ systems supply body cells with all the substances they need and eliminate their wastes. They also keep temperature, pH, and other conditions at just the right levels to support life processes.

Maintaining Homeostasis

Homeostasis (The process in which organ systems work to maintain a stable internal environment) requires constant adjustments. Here are just three of the many ways that human organ systems help the body maintain homeostasis:

- Respiratory system: A high concentration of carbon dioxide in the blood triggers faster breathing. The lungs exhale more frequently, which removes carbon dioxide from the body more quickly.
- Excretory system: A low level of water in the blood triggers retention of water by the kidneys. The kidneys produce more concentrated urine, so less water is lost from the body.
- Endocrine system: A high concentration of sugar in the blood triggers secretion of insulin by an endocrine gland called the pancreas. Insulin is a hormone that helps cells absorb sugar from the blood.

Failure of Homeostasis

Many homeostatic mechanisms work continuously to maintain stable conditions in the human body. Sometimes, however, the mechanisms fail. When they do, cells may not get everything they need, or toxic wastes may accumulate in the body. If homeostasis is not restored, the imbalance may lead to disease or even death.

Check out this video about homeostasis: http://go.uen.org/b1B

Think like a Biologist

1. Describe four different types of specialized tissues.
2. Compare the level of organization between eukaryotic and prokaryotic organisms and relate the structure of the organism to its function in an environment.
3. Explain how glucose levels are maintained in humans.

Organ Systems of the Human Body: What makes you tick?

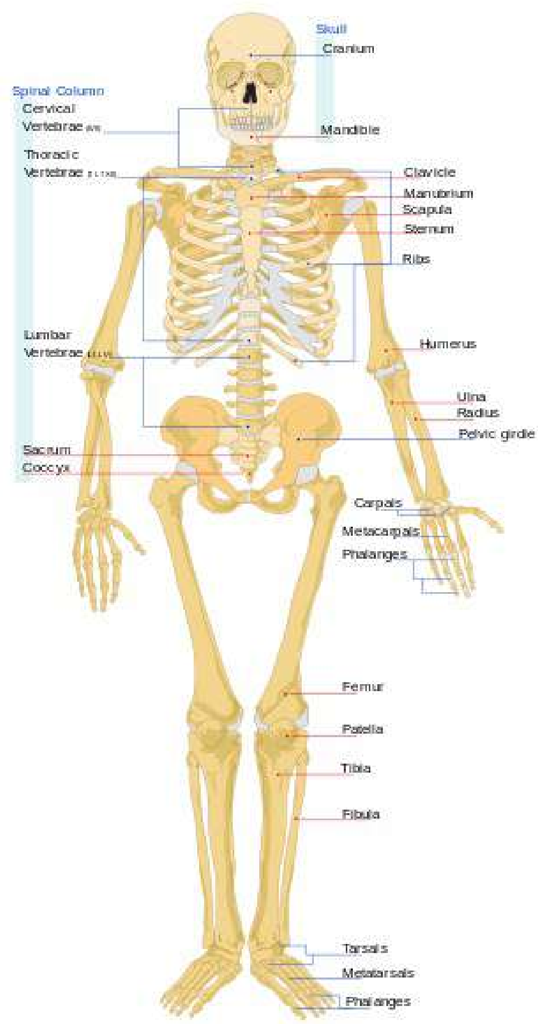
Objective

- Relate the function of the organ to the function (or the purpose the organ serves in the organism) of the organ system
- Describe the structure (the arrangement of and relations between the parts of the organism) and function of various organ systems and how these systems contribute to the homeostasis of the organism.

The Skeletal System

The skeletal system consists of all the bones of the body. Its primary function is to maintain the stability and shape of the body. Without the skeletal system, the body would have no consistent shape, and would also lack much of its immune system. Its purpose is to protect many parts of the body as well.

The human skeleton is an internal framework that, in adults, consists of 206 bones, most of which are shown in the next figure..



In addition to bones, the skeleton also consists of cartilage and ligaments.

- Cartilage is a type of dense connective tissue, made of tough protein fibers, that provides a smooth surface for the movement of bones at joints.
- A ligament is a band of fibrous connective tissue that holds bones together and keeps them in place.

The human skeleton consists of bones, cartilage, and ligaments.

The skeleton supports the body and gives it shape. It has several other functions as well, including:

- protecting internal organs
- providing attachment surfaces for muscles
- producing blood cells

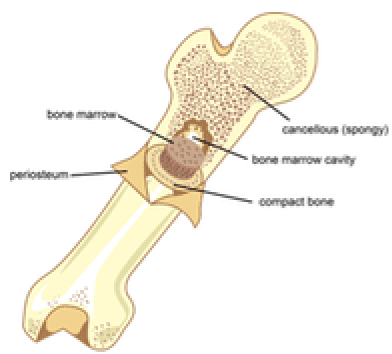
- storing minerals
- maintaining mineral homeostasis

Maintaining mineral homeostasis is a very important function of the skeleton, because just the right levels of calcium and other minerals are needed in the blood for normal functioning of the body. When mineral levels in the blood are too high, bones absorb some of the minerals and store them as mineral salts, which is why bones are so hard. When blood levels of minerals are too low, bones release some of the minerals back into the blood, thus restoring homeostasis of the blood. If there continues to be a deficiency of minerals, this may cause the bones to continue to lose minerals and bone tissue will deteriorate resulting in decreased function of the entire skeletal system.

Bone Tissues

Bones consist of different types of tissue, including compact bone, spongy bone, bone marrow, and periosteum. All of these tissue types are shown in the figure.

- Compact bone makes up the dense outer layer of bone. It is very hard and strong.
- Spongy bone is found inside bones and is lighter and less dense than compact bone. This is because spongy bone is porous.
- Bone marrow is a soft connective tissue that produces blood cells. It is found inside the pores of spongy bone.
- Periosteum is a tough, fibrous membrane that covers and protects the outer surfaces of bone.



This bone contains different types of bone tissue.

Joints

A joint is a place where two or more bones of the skeleton meet. With the help of muscles, joints work like mechanical levers, allowing the body to move with relatively little force. The surfaces of bones at joints are covered with a smooth layer of cartilage that reduces friction at the points of contact between the bones.

Muscular System

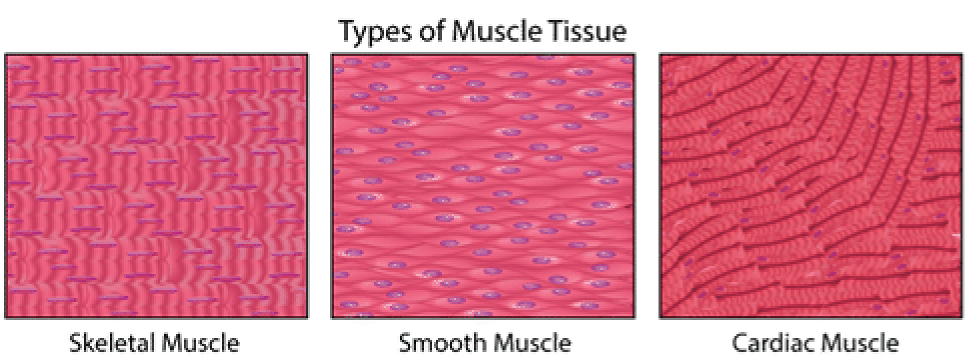
The muscular system consists of all the muscles of the body. Muscles such as biceps that move the body are easy to feel and see (See Figure), but they aren't the only muscles in the human body. Many muscles are deep within the body. They form the walls of internal organs such as the heart and stomach. Different types of muscles work together to maintain a stable environment for the human body.

This weightlifter works hard to build big muscles in his upper arms.

What Are Muscles?

Muscles are organs composed mainly of muscle cells, which are also called muscle fibers. Each muscle fiber is a very long, thin cell that can do something no other cell can do. It can contract, or shorten. Muscle contractions are responsible for virtually all the movements of the body, both inside and out. There are three types of muscle tissues in the human body: cardiac, smooth, and skeletal muscle tissues. (See figure) You can also watch an overview of the three types at this link:

- http://go.uen.org/b1C



Types of Muscle Tissue. This artist's rendition shows that both skeletal and cardiac muscles appear striated, or striped, because their cells are arranged in bundles. Smooth muscles are not striated because their cells are arranged in sheets instead of bundles.

Smooth Muscle

Muscle tissue in the walls of internal organs such as the stomach and intestines is smooth muscle. When smooth muscle contracts, it helps the organs carry out their functions. For example, when smooth muscle in the stomach contracts, it squeezes the food inside the stomach, which helps break the food into smaller pieces. Contractions of smooth muscle are involuntary. This means they are not under conscious control.

Skeletal Muscle

Muscle tissue that is attached to bone is skeletal muscle. Whether you are blinking your eyes or running a marathon, you are using skeletal muscle. Contractions of skeletal muscle are voluntary, or under conscious control. There are well over 600 skeletal muscles in the human body. Skeletal muscles vary considerably in size, from tiny muscles inside the middle ear to very large muscles in the upper leg.

Cardiac Muscle

Cardiac muscle is found only in the walls of the heart. When cardiac muscle contracts, the heart beats and pumps blood. Cardiac muscle contains a great many mitochondria, which produce ATP for energy. This helps the heart resist fatigue. Contractions of cardiac muscle are involuntary like those of smooth muscle.

Integumentary System: What is the largest organ in your body?

Did you know that you see the largest organ in your body every day? You wash it, dry it, cover it up to stay warm or uncover it to cool off. In fact, you see it so often it is easy to forget the important role your skin plays in keeping you healthy.

Your skin is part of your integumentary system (See figure), which is the outer covering of your body. The integumentary system is made up of your skin, hair, and nails. Your integumentary system has many roles in homeostasis, including protection, the sense of touch, and controlling body temperature.

Skin acts as a barrier that stops water and other things, like soap and dirt, from getting into your body.

Functions of Skin

Your skin covers the entire outside of your body. Your skin is your body's largest organ, yet it is only about 2 millimeters thick. It has many important functions. The skin:

- Provides a barrier. It keeps organisms that could harm the body out. It stops water from leaving the body, and stops water from getting into the body.
- Controls body temperature. It does this by making sweat, a watery substance that cools the body when it evaporates.
- Gathers information about your environment. Special nerve endings in your skin sense heat, pressure, cold and pain.
- Helps the body get rid of some types of waste, which are removed in sweat.
- Acts as a sunblock. A chemical called melanin is made by certain skin cells when they are exposed to sunlight. Melanin blocks sunlight from getting to deeper layers of skin cells, which are easily damaged by sunlight.

Structure of Skin

Your skin is always exposed to your external environment, so it gets cut, scratched, and worn down. You also naturally shed many skin cells every day. Your body replaces damaged or missing skin cells by growing more of them. Did you know that the layer of skin you can see is actually dead? The dead cells are filled with a tough, waterproof

protein called keratin. As the dead cells are shed or removed from the upper layer, they are replaced by the skin cells below them.

Skin is made up of two layers, the epidermis on top and the dermis below. The tissue below the dermis is called the hypodermis, but it is not part of the skin.

The color, thickness and texture of skin vary over the body. There are two general types of skin:

- Thin and hairy, which is the most common type on the body.
- Thick and hairless, which is found on parts of the body that experience a lot of contact with the environment, such as the palms of the hands or the soles of the feet.

The Epidermis

The epidermis (the outermost layer of the skin) forms the waterproof, protective wrap over the body's surface. The epidermis is divided into several layers of epithelial cells. The epithelial cells are formed by mitosis in the lowest layer. These cells move up through the layers of the epidermis to the top. Although the top layer of epidermis is only about as thick as a sheet of paper, it is made up of 25 to 30 layers of cells.

The epidermis also contains cells that produce melanin-(a protein that provides pigment) is the brownish pigment that gives skin and hair their color. Melanin-producing cells are found in the bottom layer of the epidermis.

The epidermis does not have any blood vessels. The lower part of the epidermis receives blood by diffusion from blood vessels of the dermis.

The Dermis

The dermis (the layer of skin directly under the epidermis) is made of a tough connective tissue that contains the protein collagen. Collagen is a long, fiber-like protein that is very strong. The dermis is tightly connected to the epidermis by a thin wall of collagen fibers.

The dermis contains hair follicles, sweat glands, oil glands, and blood vessels. It also holds many nerve endings that give you your sense of touch, pressure, heat, and pain.

Do you ever notice how your hair stands up when you are cold or afraid? Tiny muscles in the dermis pull on hair follicles which cause hair to stand up. The resulting little bumps in the skin are commonly called “goosebumps”, (See figure)

Goosebumps are caused by tiny muscles in the dermis that pull on hair follicles, which causes the hairs to stand up straight.

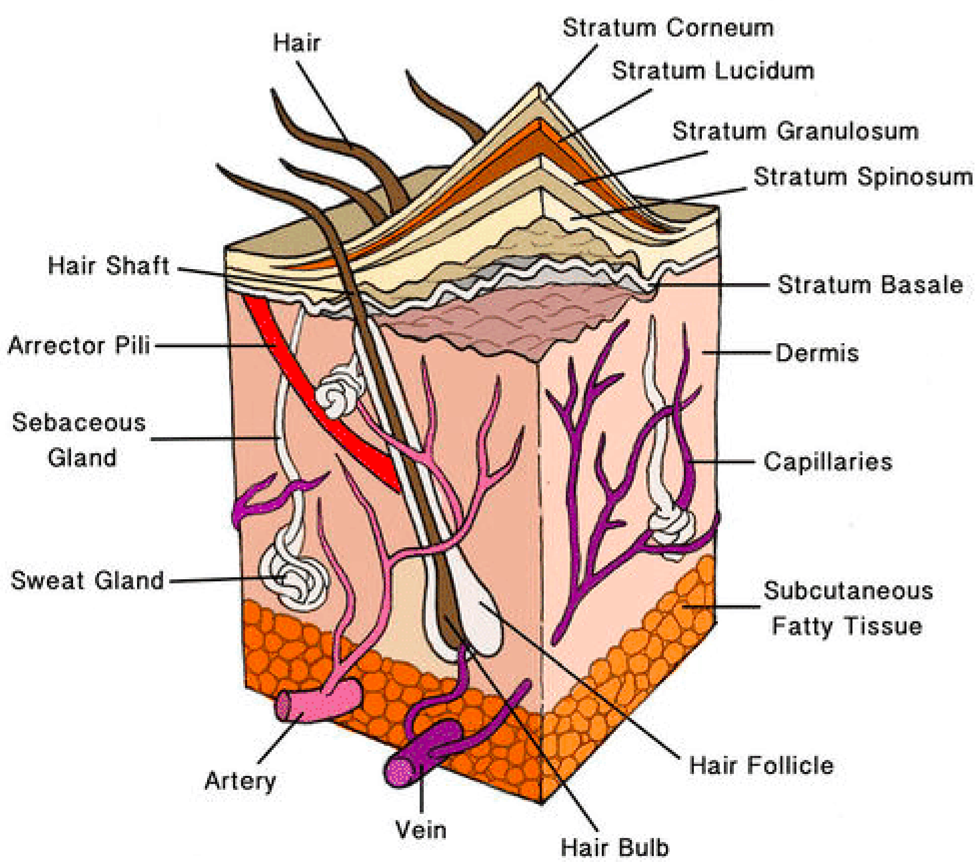
Oil Glands and Sweat Glands

Glands and follicles open out into the epidermis, but they start in the dermis. Oil glands (small organs that produce oil) release, or secrete, an oily substance, called sebum, into the hair follicle. Sebum "waterproofs" hair and the skin surface to prevent them from drying out. It can also stop the growth of bacteria on the skin. It is odorless, but the breakdown of sebum by bacteria can cause odors. If an oil gland becomes plugged and infected, it develops into a pimple. Up to 85% of teenagers get pimples, which usually go away by adulthood. Frequent washing can help decrease the amount of sebum on the skin.

Sweat glands (small organs that produce sweat) open to the skin surface through skin pores. They are found all over the body. Evaporation of sweat from the skin surface helps to lower skin temperature. This is why sweat can help maintain homeostasis. The skin also releases excess water, salts, and other wastes in sweat.

Hair

Hair sticks out from the epidermis, but it grows from the dermis (See figure). Hair is also made of keratin, the same protein that makes up skin and nails. Hair grows from inside the hair follicle. New cells grow in the bottom part of the hair, called the bulb. Older cells get pushed up, and the hair grows longer. Similar to nails and skin, the cells that make up the hair strand are dead and filled with keratin.



Hair, hair follicle, and oil glands. The oil, called sebum, helps to prevent water loss from the skin.

Hair helps to keep the body warm. When you feel cold, your skin gets a little bumpy. These bumps are caused by tiny muscles that pull on the hair, causing the hair to stick out. The erect hairs help to trap a thin layer of air that is warmed by body heat. In mammals that have much more hair than humans, the hair traps a layer of warm air near the skin and acts like warm blanket. Hair also protects the skin from ultraviolet (UV) radiation from the sun.

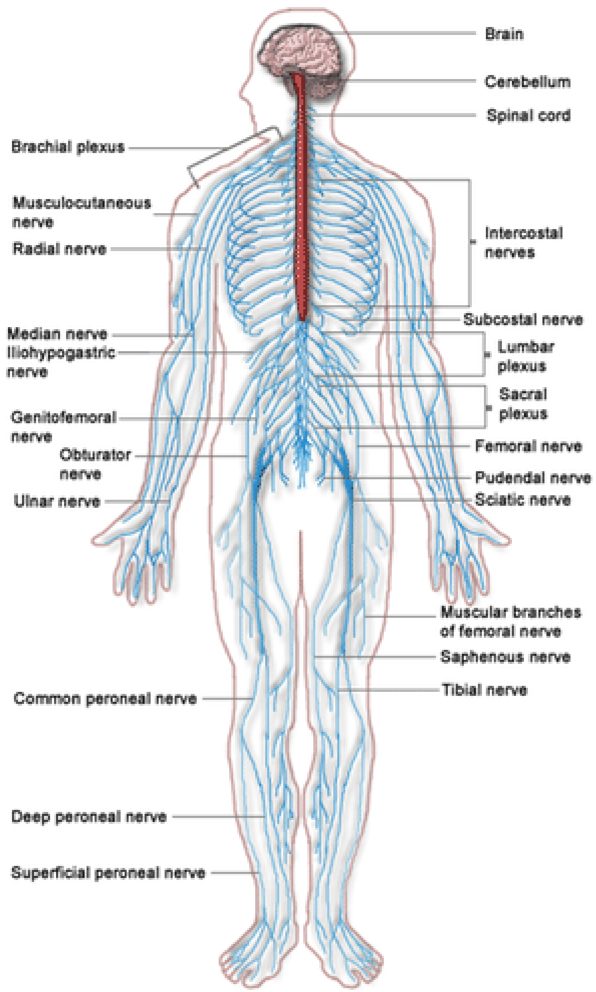
Hair also acts as a filter. Nose hair helps to trap particles in the air that may otherwise travel to the lungs. Eyelashes shield eyes from dust and sunlight. Eyebrows stop salty sweat and rain from flowing into the eye.

You can watch animations of the two layers of skin and how they function at these links:

- http://go.uen.org/b1D

Nervous System: How does it work so fast?

The nervous system is a complex network of nervous tissue that carries electrical messages throughout the body (see figure). These messages allow organisms to rapidly respond to changes in their environment, as well as to maintain normally functions of organs and tissues. To understand how nervous messages can travel so quickly, you need to know more about nerve cells.



The human nervous system includes the brain and spinal cord (central nervous system) and nerves that run throughout the body (peripheral nervous system).

Central Nervous System

The nervous system has two main divisions: the central nervous system and the peripheral nervous system (see figure). The central nervous system (CNS) includes the brain and spinal cord.

You can see an overview of the central nervous system at this link:

- http://go.uen.org/b1E

The Brain

The brain is the most complex organ of the human body and the control center of the nervous system. It contains an astonishing 100 billion neurons. The brain controls such mental processes as reasoning, imagination, memory, and language. It also interprets information from the senses. In addition, it controls basic physical processes such as breathing and heartbeat. The brain has three major parts: the cerebrum, cerebellum, and brainstem. These parts are shown in the next figure.
You can also take interactive animated tours of the brain at these links:

- http://go.uen.org/b1F

Spinal Cord

The spinal cord is a thin, tubular bundle of nervous tissue that extends from the brainstem and continues down the center of the back to the pelvis. It is protected by the vertebrae, which encase it. The spinal cord serves as an information superhighway, passing messages from the body to the brain and from the brain to the body.

Peripheral Nervous System

The peripheral nervous system (PNS) consists of all the nervous tissue that lies outside the central nervous system. It is connected to the central nervous system by nerves. A nerve is a cable-like bundle of axons. Some nerves are very long. The longest human nerve is the sciatic nerve. It runs from the spinal cord in the lower back down the left leg all the way to the toes of the left foot.

Circulatory System: How do materials move around my body?

The function of the circulatory system is to move materials around the body. The materials carried by the circulatory system include hormones, oxygen, cellular wastes, and nutrients from digested food. Transport of all these materials is necessary to maintain homeostasis of the body. The main components of the circulatory system are the heart, blood vessels, and blood.

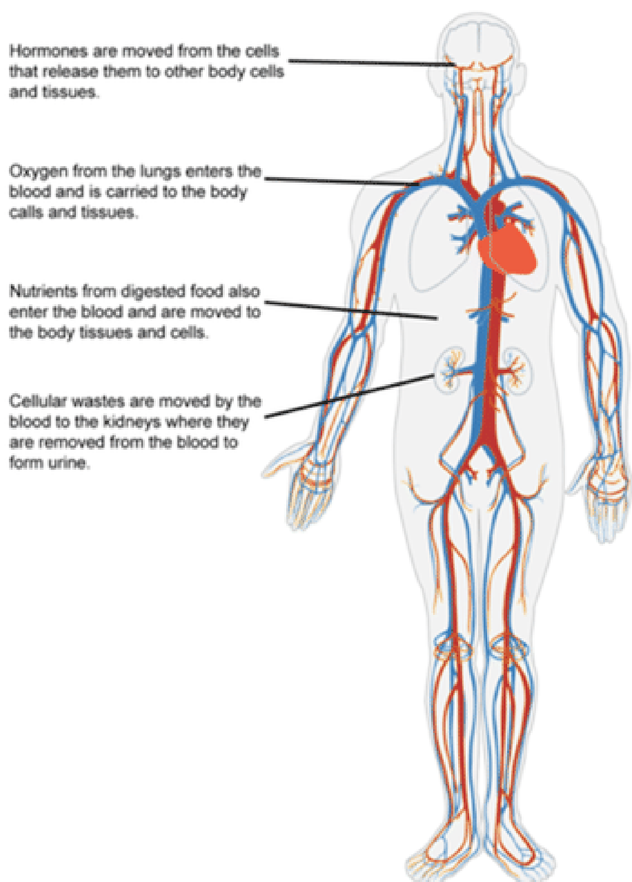
The heart is a muscular organ in the chest. It consists mainly of cardiac muscle tissue and pumps blood through blood vessels by repeated, rhythmic contractions. The heart has four chambers: two upper atria (singular, atrium) and two lower ventricles. Valves between chambers keep blood flowing through the heart in just one direction.

For an animation of the structures of the heart, go to this link:

- http://go.uen.org/b1G

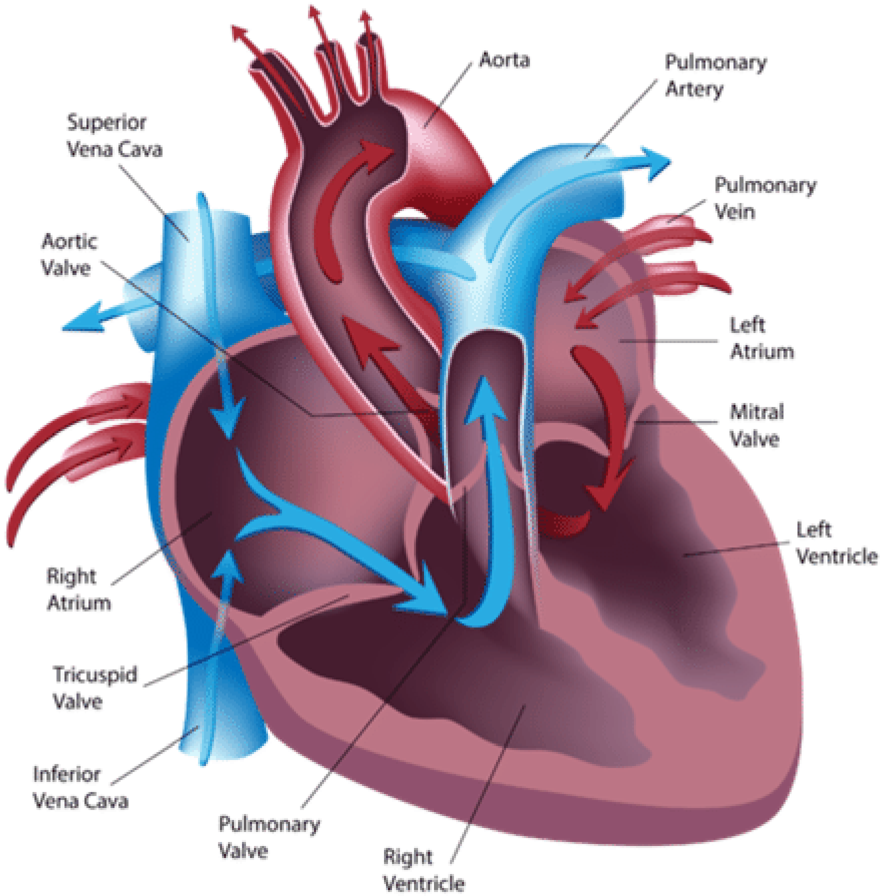
For a Prezi presentation on the four chambers of the heart go to this link:

- http://go.uen.org/b1H



Blood flows through the heart in two separate loops, which are indicated by the arrows in the figure above.

The following link is an animation of the heart pumping blood:
http://go.uen.org/b1I



The chambers of the heart and the valves between them are shown here.

Blood from the body enters the right atrium of the heart. The right atrium pumps the blood to the right ventricle, which pumps it to the lungs. This loop is represented by the blue arrows in the Figure above.

Blood from the lungs enters the left atrium of the heart. The left atrium pumps the blood to the left ventricle, which pumps it to the body. This loop is represented by the red arrows in the Figure above.

Heartbeat

Unlike skeletal muscle, cardiac muscle contracts without stimulation by the nervous system. Instead, specialized cardiac muscle cells send out electrical impulses that stimulate the contractions. As a result, the atria and ventricles normally contract with just the right timing to keep blood pumping efficiently through the heart.

The following link provides an animation of this process:

- http://go.uen.org/b1J

Blood Vessels

Blood vessels form a network throughout the body to transport blood to all the body cells. There are three major types of blood vessels: arteries, veins, and capillaries. All three are shown in the Figure below and described below.

Arteries are muscular blood vessels that carry blood away from the heart. They have thick walls that can withstand the pressure of blood being pumped by the heart. Arteries generally carry oxygen-rich blood. The largest artery is the aorta, which receives blood directly from the heart.

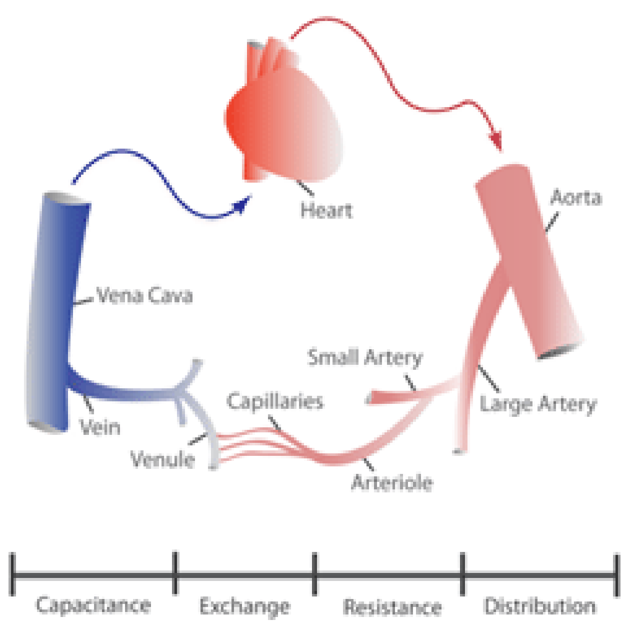
Veins are blood vessels that carry blood toward the heart. This blood is no longer under much pressure, so many veins have valves that prevent backflow of blood. Veins generally carry deoxygenated blood. The largest vein is the inferior vena cava, which carries blood from the lower body to the heart.

Capillaries are the smallest type of blood vessels. They connect very small arteries and veins. The exchange of gases and other substances between cells and the blood takes place across the extremely thin walls of capillaries.

Blood vessels include arteries, veins, and capillaries.

For more information on the heart and circulatory system.

- http://go.uen.org/b1J
- http://go.uen.org/b1K



Think like a Heart Surgeon

1. How does the form/structure of the circulatory system relate to its function?

2. Analyze the effect that increasing an organism's level of activity (e.g. running vs walking) has on the function of the heart.

3. Relate the function of the heart to homeostasis in a living organism.

4. Determine the effect of constriction of blood vessels on the nervous system.

5. Argue the use of the artificial heart in treating heart patients.

Respiratory System: How does the rest of my body get oxygen?

Introduction

Red blood cells carry oxygen throughout the body. This oxygen is brought into the body through the lungs, the main organ of the respiratory system. This is body system brings air containing oxygen into the body and releases carbon dioxide into the atmosphere.

Respiration

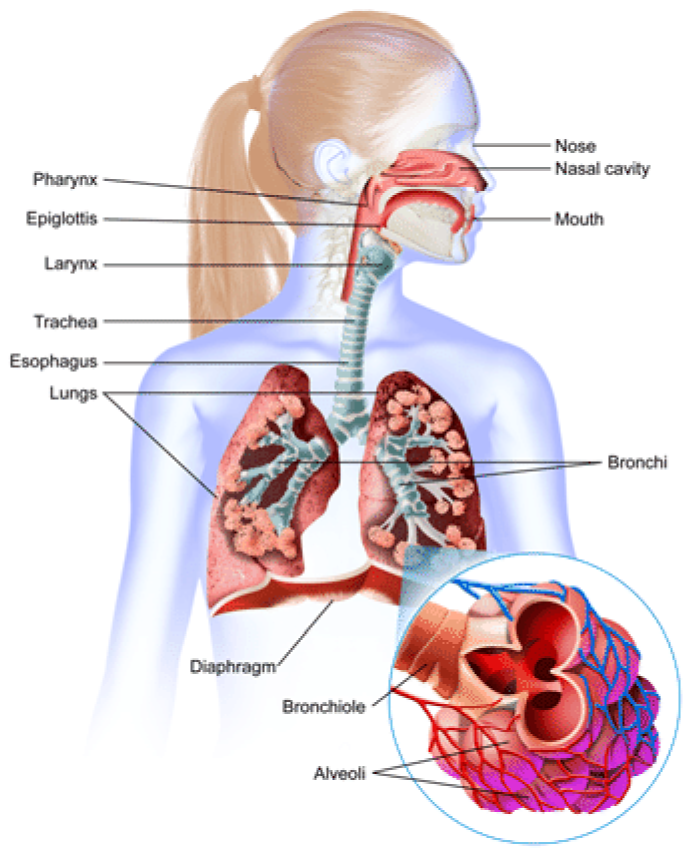
The job of the respiratory system is the exchange of gases between the body and the outside air. This process, called respiration, actually consists of two parts. In the first part, oxygen in the air is drawn into the body and carbon dioxide is released from the body through the respiratory tract. In the second part, the circulatory system delivers the oxygen to body cells and picks up carbon dioxide from the cells in return. The use of the word respiration in relation to gas exchange is different from its use in the term cellular respiration. Recall that cellular respiration is the metabolic process by which cells obtain energy by "burning" glucose. Cellular respiration uses oxygen and releases carbon dioxide. Respiration by the respiratory system supplies the oxygen and takes away the carbon dioxide.

An overview of breathing is shown at: http://go.uen.org/b1N

Organs of the Respiratory System

The organs of the respiratory system that bring air into the body are shown in the figure on the following page. Refer to the figure as you read below about the passage of air through these organs.

The organs of the respiratory system move air into and out of the body. The main organ is the lungs. Lungs are not just balloon-like air sacs. The lungs are made up of millions of tiny air sacs, and resemble an upside down tree. The trachea is like the trunk that branches to your two lungs.



The lungs are lined with mucus, which is a secretion produced by the cells that line the airways. Mucus helps wet the air and traps dust and dirt to help keep the lungs clean.

Other structures in the respiratory system include: the pharynx, the tube in back of the nose and mouth where the nose passages and mouth cavity meet; the larynx, or voice box; vocal cords; and windpipe. There is a slit-like opening called the glottis between the vocal cords.

The tube that attaches to the larynx is the main breathing tube or windpipe called the trachea.

To keep food and drink from going into the trachea, a trap door called the epiglottis sits over the larynx. It closes when you eat or drink to keep food out of the airways. But it opens when you breathe in or cough out. This flap-like trap door is called the epiglottis. The walls of the trachea contain rings of cartilage. Even from the outside you can feel the trachea in the front, low part of the neck. Below these rings of cartilage the trachea branches into two tubes – one tube for each lung. These tubes are called the bronchi. Like a branching tree, each of the bronchi branches again and again into smaller tubes called bronchioles. Each time the tube branches, it gets smaller. The smallest parts of the lungs are clusters of air sacs called alveoli. When you get a really bad cold, your airways get infected. That infection is called bronchitis since it is the bronchi and bronchioles that are being attacked by the cold virus or bacteria.

Digestive System: How does my body get rid of waste?

The respiratory and circulatory systems work together to provide cells with the oxygen they need for cellular respiration. Cells also need glucose for cellular respiration. Glucose is a simple sugar that comes from the food we eat. To get glucose from food, digestion must occur. This process is carried out by the digestive system.

Overview of the Digestive System

The digestive system consists of organs that break down food and absorb nutrients such as glucose. Most of the organs make up the gastrointestinal tract. The rest of the organs are called accessory organs.

Stomach

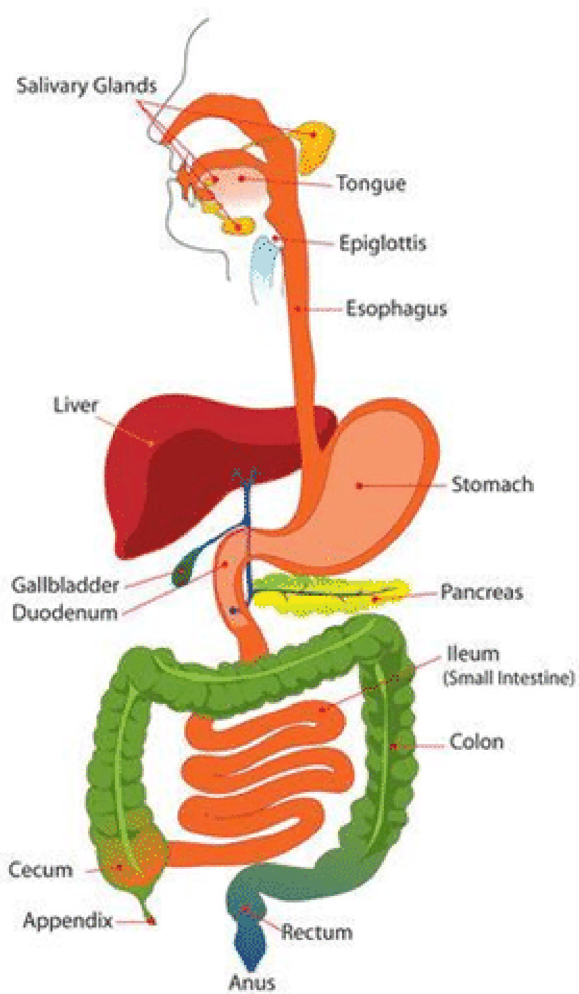
The stomach is a sac-like organ in which food is further digested both mechanically and chemically. Churning movements of the stomach's thick, muscular walls complete the mechanical breakdown of food. The churning movements also mix food with digestive fluids secreted by the stomach. One of these fluids is hydrochloric acid. It kills bacteria in food and gives the stomach the low pH needed by digestive enzymes that work in the stomach. The main enzyme is pepsin, which chemically digests protein.

For additional information, see: http://go.uen.org/b1T

The stomach stores the partly digested food until the small intestine is ready to receive it. When the small intestine is empty, a sphincter opens to allow the partially digested food to enter the small intestine.

Digestion and Absorption: The Small Intestine

The small intestine is a narrow tube about 7 meters (23 feet) long in adults. It is the site of most chemical digestion and virtually all absorption of nutrients in the body. The liver is an organ of both digestion and excretion. It produces a fluid called bile which is secreted into the small intestine. Some bile also goes to the gallbladder, a sac-like organ that stores and concentrates bile and then secretes it into the small intestine. Bile also reduces the acidity of food entering from the highly acidic stomach. The pancreas contributes to the neutral environment by secreting bicarbonate, a basic substance that neutralizes acid. The digestive system includes organs from the mouth to the anus. (See figure)



The Large Intestine and Its Functions

From the small intestine, any remaining food wastes pass into the large intestine. The large intestine is a relatively wide tube that connects the small intestine with the anus. Like the small intestine, the large intestine also consists of three parts: the cecum (or caecum), colon, and rectum.

Absorption of Water and Elimination of Wastes

The cecum is the first part of the large intestine, where wastes enter from the small intestine. The wastes are in a liquid state. As they pass through the colon, which is the second part of the large intestine, excess water is absorbed. The remaining solid wastes are called feces. Feces accumulate in the rectum, which is the third part of the large intestine. As the rectum fills, the feces become compacted. After a certain amount of feces accumulate, they are eliminated from the body. A sphincter controls the anus and opens to let feces pass through.

Excretory System

If you exercise on a hot day, you are likely to lose a lot of water in sweat. Then, for the next several hours, you may notice that you do not pass urine as often as normal and that your urine is darker than usual. Do you know why this happens? Your body is low on water and trying to reduce the amount of water lost in urine. The amount of water lost in urine is controlled by the kidneys, the main organs of the excretory system.

Excretion

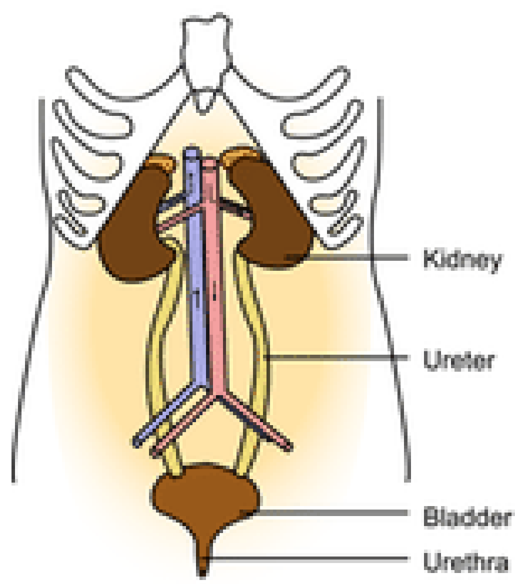
Excretion is the process of removing wastes and excess water from the body. It is one of the major ways the body maintains homeostasis. Although the kidneys are the main organs of excretion, several other organs also excrete wastes. They include the large intestine, liver, skin, and lungs. All of these organs of excretion, along with the kidneys, make up the excretory system. The roles of the other excretory organs are summarized below:

- The large intestine eliminates solid wastes that remain after the digestion of food.
- The liver breaks down excess amino acids and toxins in the blood.
- The skin eliminates excess water and salts in sweat.
- The lungs exhale water vapor and carbon dioxide.

The kidneys are part of the urinary system, a part of the excretory system. (See figure) The main function of the excretory system is to filter waste products and excess water from the blood and excrete them from the body.

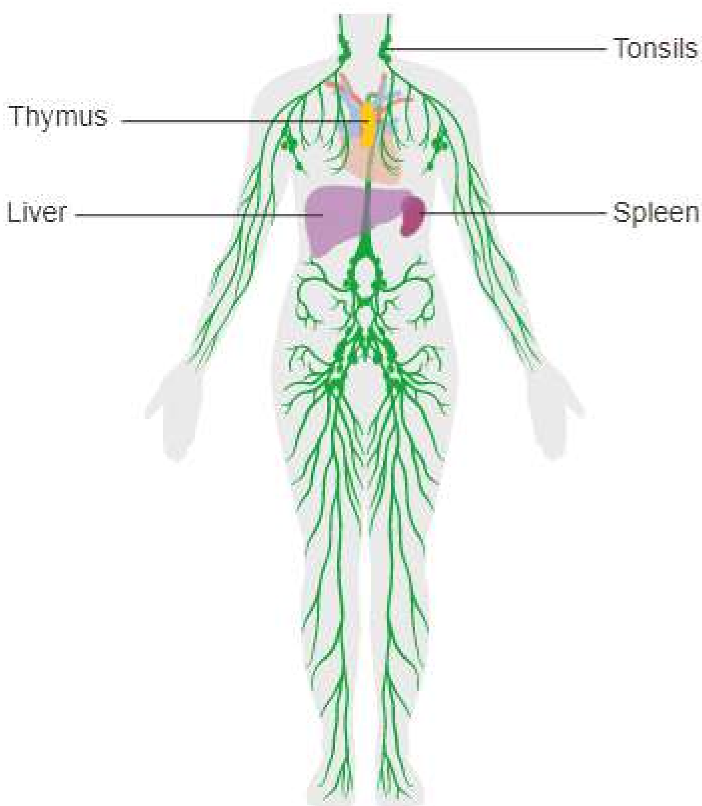
Kidneys and Nephrons

The kidneys are a pair of bean-shaped organs just above the waist. The function of the kidney is to filter blood and form urine. Urine is the liquid waste product of the body that is excreted by the excretory system. Nephrons are the structural and functional units of the kidneys. A single kidney may have more than a million nephrons.



Lymphatic System

- The structures of the lymphatic system include organs, lymph vessels, lymph, and lymph nodes. Organs of the lymphatic system are the bone marrow, thymus, spleen, and tonsils.
- Bone marrow is found inside many bones. It produces lymphocytes.
- The thymus is located in the upper chest behind the breastbone. It stores and matures lymphocytes.
- The spleen is in the upper abdomen. It filters pathogens and worn out red blood cells from the blood, and then lymphocytes in the spleen destroy them.
- The tonsils are located on either side of the pharynx in the throat. The trap pathogens, which are destroyed by lymphocytes in the tonsils.



Reproductive Systems:

Male reproductive system

Male gametes or sperm are produced in the testes to be used for fertilization in sexually reproducing organisms.

Female Reproductive system

Female gametes or eggs are stored in the ovaries. When fertilization occurs the zygotes become embedded in the uterus.

Summary

All of the organ systems in humans and other organisms are complex and multifaceted, but work together to maintain homeostasis and provide the ability to maintain an active and healthy life. While the functions may vary for each system, they rely on each other to provide the processes and stability necessary for growth, life and reproduction.

Online Interactives/Simulations

Interactive game on the Endocrine System.

- http://go.uen.org/b1U

Interactive game on Immunity and Homeostasis.

- http://go.uen.org/b1V

3.2 Comparing Organ Systems

Fish Organ Systems: How many chambers are in their heart?

Fish have a circulatory system with a two-chambered heart. Their digestive system is complete and includes several organs and glands. Jawed fish use their jaws and teeth to grind up food before passing it to the rest of the digestive tract. This allows them to consume larger prey.

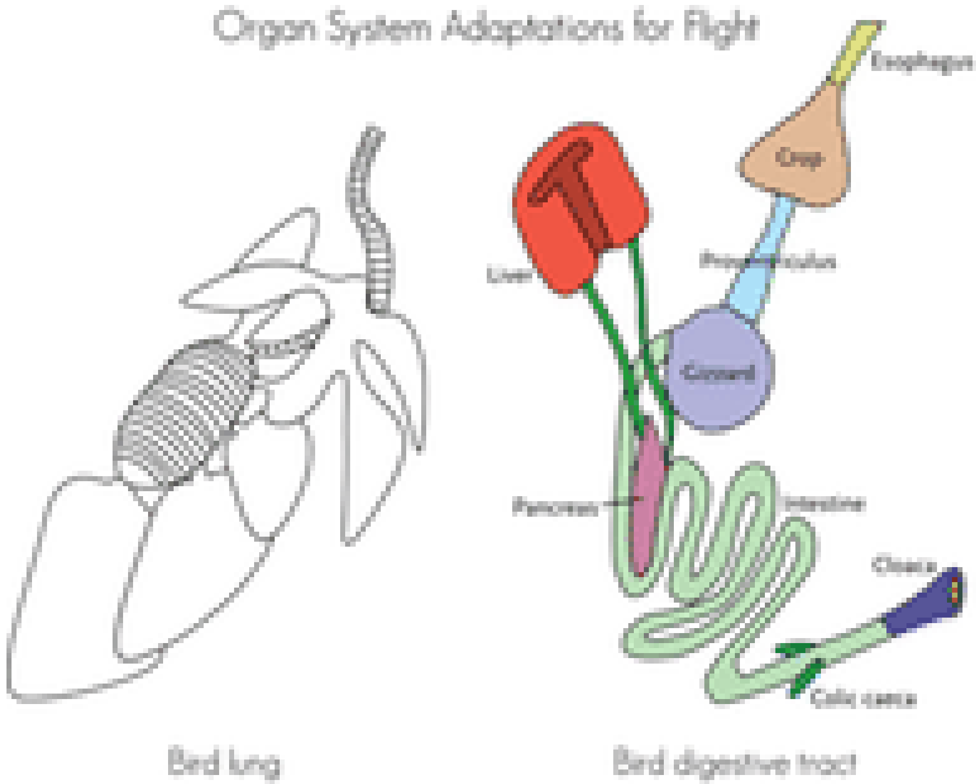
Fish also have a centralized nervous system with a brain. Fish brains are small compared with the brains of other vertebrates, but they are large and complex compared with the brains of invertebrates. Fish also have highly developed sense organs that allow them to see, hear, feel, smell, and taste. Sharks and some other fish can even sense the very low levels of electricity emitted by other animals. This helps them locate prey.

- http://go.uen.org/b1X

Bird Organ Systems: How are their bones different?

Birds need a lightweight body in order to stay aloft. Even so, flying is hard work, and flight muscles need a constant supply of oxygen-and nutrient-rich blood. The organ systems of birds are adapted to meet these needs.

- Birds have lightweight bones that are filled with air. They also lack a jaw, which in many vertebrates is a dense, heavy bone with many teeth. Instead, birds have a light-weight keratin beak without teeth.
- Birds have air sacs that store inhaled air and push it into the lungs like bellows. This keeps the lungs constantly filled with oxygenated air. The lungs also contain millions of tiny passages that create a very large surface area for gas exchange with the blood.
- Birds have a relatively large, four-chambered heart. The heart beats rapidly to keep oxygenated blood flowing to muscles and other tissues. Hummingbirds have the fastest heart rate at up to 1,200 beats per minute. That's almost 20 times faster than the human resting heart rate!
- Birds have a sac-like structure called a crop to store and moisten food that is waiting to be digested. They also have an organ called a gizzard that contains swallowed stones. The stones make up for the lack of teeth by grinding food, which can then be digested more quickly. Both structures make it easier for the digestive system to produce a steady supply of nutrients from food.



Organ System Adaptations for Flight. The intricate passageways in a bird's lung are adapted for efficient gas exchange. Find the crop and gizzard in the digestive tract diagram. What are their functions? Bird Lung (left), Bird Digestive Tract (right)

Nervous System and Sense Organs

Birds have a large brain relative to the size of their body. Not surprisingly, the part of the brain that controls flight is the most developed part. The large brain size of birds is also reflected by their high level of intelligence and complex behavior. In fact, birds such as crows and ravens may be more intelligent than many mammals. They are smart enough to use objects such as twigs for tools. They also demonstrate planning and cooperation.

Most birds have a poor sense of smell, but they make up for it with their excellent sense of sight. Predatory birds have especially good eyesight. Hawks, for example, have vision that is eight times sharper than human vision.

- http://go.uen.org/b1Y

Insect specific organ systems

An insect's abdomen contains most of the internal organs. Like other arthropods, insects have a complete digestive system. They also have an open circulatory system and central nervous system. Like other terrestrial arthropods, they have trachea for breathing air and Malpighian tubules for excretion.

Organ System	Major Tissues and Organs	Function
Cardiovascular	Heart; blood vessels; blood	Transports oxygen, hormones, and nutrients to the body cells. Moves wastes and carbon dioxide away from cells.
Lymphatic	Lymph nodes; lymph vessels	Defend against infection and disease, moves lymph between tissues and the blood stream.
Digestive	Esophagus; stomach; small intestine; large intestine	Digests foods and absorbs nutrients, minerals, vitamins, and water.
Endocrine	Pituitary gland, hypothalamus; adrenal glands; ovaries; testes	Produces hormones that communicate between cells.
Integumentary	Skin, hair, nails	Provides protection from injury and water loss, physical defense against infection by microorganisms and temperature control.
Muscular	Cardiac (heart) muscle; skeletal muscle; smooth muscle; tendons	Involved in movement and heat production
Nervous	Brain, spinal cord; nerves	Collects, transfers, and processes information
Reproductive	Female: uterus; vagina; fallopian tubes; ovaries Male: penis; testes; seminal vesicles	Produces gametes (sex cells) and sex hormones

Respiratory	Trachea, larynx, pharynx, lungs	Brings air to sites where gas exchange can occur between the blood and cells (around body) or blood and air (lungs).
Skeletal	Bones, cartilage; ligaments	Supports and protects soft tissues of body; produces blood cells; stores minerals.
Urinary	Kidneys; urinary bladder	Removes extra water, salts, and waste products from blood and body; controls pH; controls water and salt balance.
Immune	Bone marrow; spleen; white blood cells	Defends against diseases

Think like a Physiologist

1. Which organ system plays the largest role in providing protection for the body?
2. Which organ is most closely involved in regulating the movement and response of the body?
3. What is the difference between respiration and cellular respiration?
4. What are the three parts of the small intestine?
5. What are the two types of muscle tissue?
6. How would a spinal cord injury affect the functioning of the nervous system?
7. Explain how a heart attack might disrupt the circulatory system.

Technological Advancements in Organ Research

TED.com have amazing information about advancements in organ research. You can go and search any topic you might be interested in or here are a few links for you.

Growing New Organs: http://go.uen.org/b1Z

Printing a Human Kidney: http://go.uen.org/b20

3.3 Plant Tissue and Growth

Like animals, plants have organs that are specialized to carry out complex functions.

All three types of plant cells are found in most plant tissues. Three major types of plant tissues are dermal, ground, and vascular tissues.

Dermal Tissue

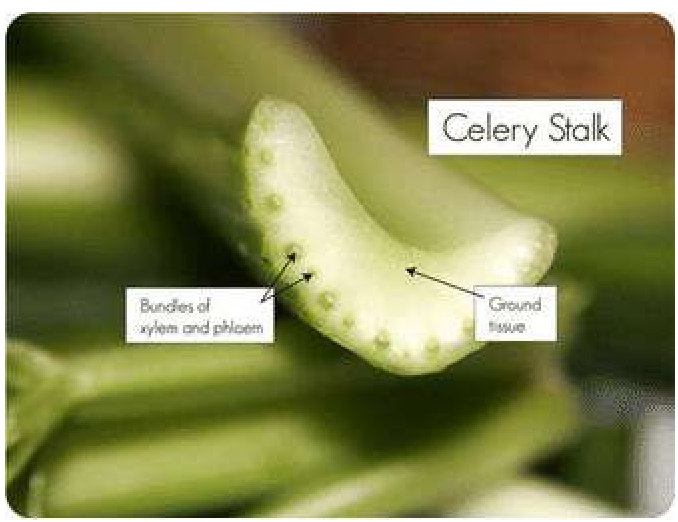
Dermal tissue covers the outside of a plant in a single layer of cells called the epidermis. You can think of the epidermis as the plant's skin. It mediates most of the interactions between a plant and its environment. Epidermal cells secrete a waxy substance called cuticle, which coats, waterproofs, and protects the parts of plants that are above ground. Cuticle helps prevent water loss, abrasions, infections, and damage from toxins.

Ground Tissue

Ground tissue makes up much of the interior of a plant and carries out basic metabolic functions. Ground tissue in stems provides support and may store food or water. Ground tissues in roots may also store food.

Vascular Tissue

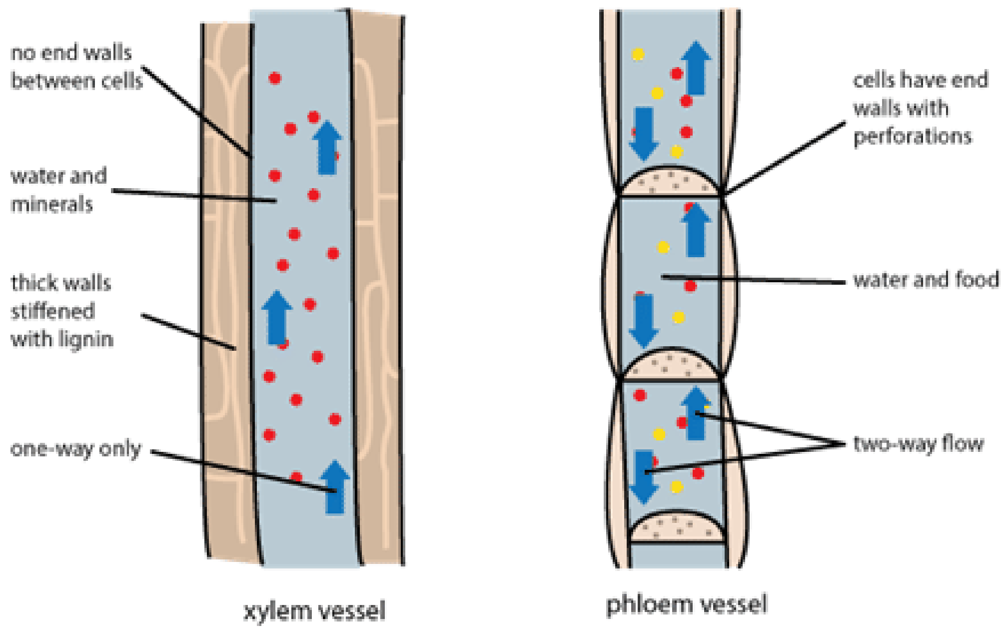
Vascular tissue runs through the ground tissue inside a plant. It consists of xylem and phloem, which transport fluids. Xylem and phloem are packaged together in bundles, as shown in the Figure below.



Bundles of xylem and phloem run through the ground tissue inside this stalk of celery. What function do these tissues serve?

Xylem is vascular tissue that transports water and dissolved minerals from roots to stems and leaves. This type of tissue consists of dead cells. The side walls are thick and reinforced with lignin, which makes them stiff and waterproof.

Phloem is vascular tissue that transports food (sugar dissolved in water) from photosynthetic cells to other parts of the plant for growth or storage. This type of tissue consists of living cells that are separated by end walls with tiny perforations, or holes.



Growth of Plants

Most plants continue to grow throughout their lives. Like other multicellular organisms, plants grow through a combination of cell growth and cell division. Cell growth increases cell size, while cell division (mitosis) increases the number of cells. As plant cells grow, they also become specialized into different cell types through cellular differentiation. Once cells differentiate, they can no longer divide. How do plants grow or replace damaged cells after that?

The key to continued growth and repair of plant cells is meristem. Meristem is a type of plant tissue consisting of undifferentiated cells that can continue to divide and differentiate. Meristem at the tips of roots and stems allows them to grow in length. This is called primary growth. Meristem within and around vascular tissues allows growth in width. This is called secondary growth.

Plant organs: What are Roots, Stems, Leaves, and Flowers?

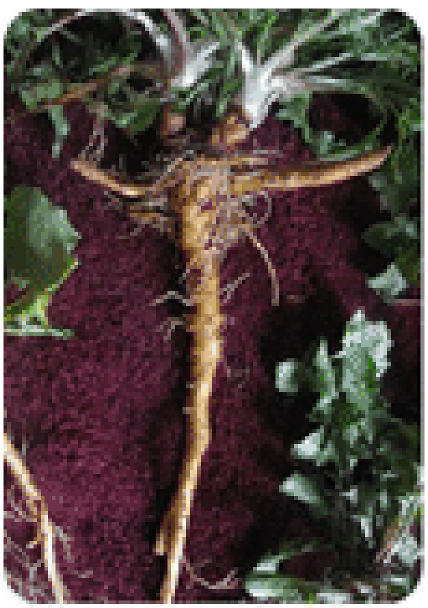
Plants have specialized organs that help them survive and reproduce in a great diversity of habitats. Major organs of most plants include roots, stems, leaves, and flowers. A plant has two organ systems: 1) the shoot system, and 2) the root system. The shoot system is above ground and includes the organs such as leaves, stems, flowers (if the plant has any), and fruits (if the plant has any). The root system includes those parts of the plant below ground, such as the roots.

Roots

Roots are important organs in all vascular plants. Most vascular plants have two types of roots: primary roots that grow downward and secondary roots that branch out to the side. Together, all the roots of a plant make up a root system.

Root Systems

There are two basic types of root systems in plants: taproot systems and fibrous root systems. Both are illustrated in the figure.



Taproot System: Dandelion

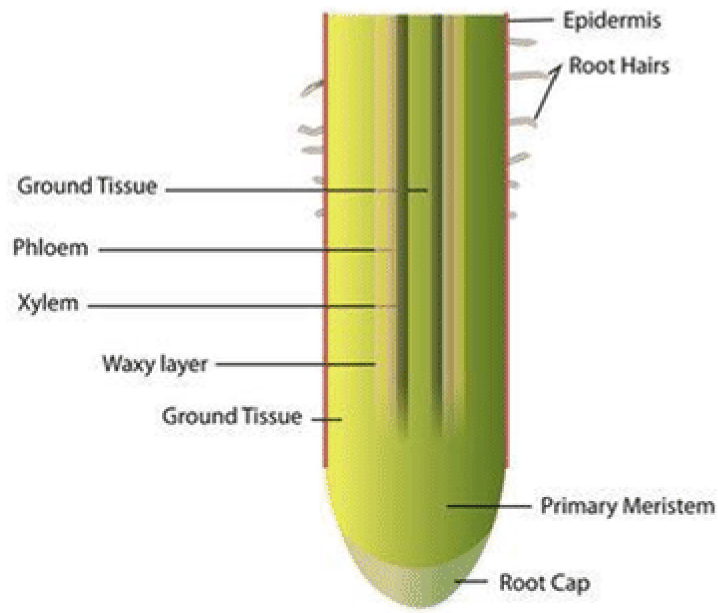
Fibrous Root System: Grass

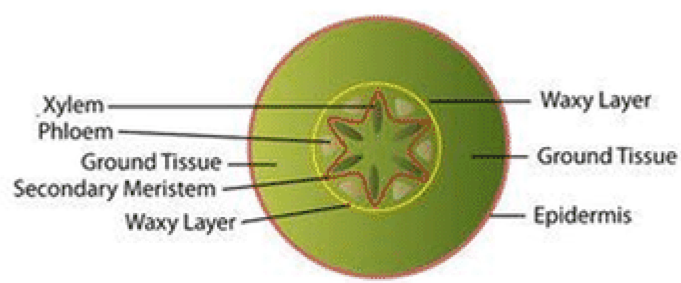
Taproot systems feature a single, thick primary root, called the taproot, with smaller secondary roots growing out from the sides. The taproot may penetrate as many as 60 meters (almost 200 feet) below the ground surface. It can plumb very deep-water

sources and store a lot of food to help the plant survive drought and other environmental extremes. The taproot also anchors the plant very securely in the ground.

Fibrous root systems have many small branching roots, called fibrous roots, but no large primary root. The huge number of threadlike roots increases the surface area for absorption of water and minerals, but fibrous roots anchor the plant less securely.

Root Structures and Functions





The tip of a root is called the root cap. It consists of specialized cells that help regulate primary growth of the root at the tip. Above the root cap is primary meristem, where growth in length occurs.

A root is a complex organ consisting of several types of tissue. What is the function of each tissue type? Above the meristem, the rest of the root is covered with a single layer of epidermal cells. These cells may have root hairs that increase the surface area for the absorption of water and minerals from the soil. Beneath the epidermis is ground

tissue, which may be filled with stored starch. Bundles of vascular tissues form the center of the root. Waxy layers waterproof the vascular tissues so they don't leak, making them more efficient at carrying fluids. Secondary meristem is located within and around the vascular tissues. This is where growth in thickness occurs.

The structure of roots helps them perform their primary functions. What do roots do? They have three major jobs: absorbing water and minerals, anchoring and supporting the plant, and storing food.

- Absorbing water and minerals: Thin-walled epidermal cells and root hairs are well suited to absorb water and dissolved minerals from the soil. The roots of many plants also have a mycorrhizal relationship with fungi for greater absorption.
- Anchoring and supporting the plant: Root systems help anchor plants to the ground, allowing plants to grow tall without toppling over. A tough covering may replace the epidermis in older roots, making them rope like and even stronger. As shown in the figure below, some roots have unusual specializations for anchoring plants.
- Storing food: In many plants, ground tissues in roots store food produced by the leaves during photosynthesis. The bloodroot shown in the figure below stores food in its roots over the winter.

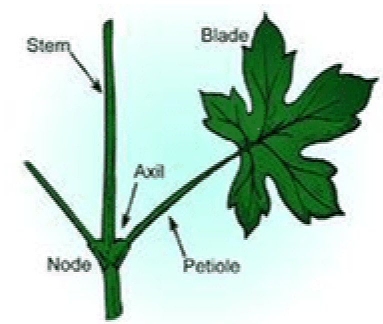
Mangrove roots are like stilts, allowing mangrove trees to rise high above the water. The trunk and leaves are above water even at high tide. A bloodroot plant uses food stored over the winter to grow flowers in the early spring.

Root Growth

Roots have primary and secondary meristems for growth in length and width. As roots grow longer, they always grow down into the ground. Even if you turn a plant upside down, its roots will try to grow downward. How do roots "know" which way to grow? How can they tell down from up? Specialized cells in root caps are able to detect gravity. The cells direct meristem in the tips of roots to grow downward toward the center of Earth. This is generally adaptive for land plants.

Stems

In vascular plants, stems are the organs that hold plants upright so they can get the sunlight and air they need. Stems also bear leaves, flowers, cones, and secondary stems. These structures grow at points called nodes (shown in the Figure below). At each node, there is a bud of meristem tissue that can divide and specialize to form a particular structure.



The stem of a vascular plant has nodes where leaves and other structures may grow.

Stem Tissues and Functions

Like roots, the stems of vascular plants are made of dermal, vascular, and ground tissues.

- A single-celled layer of epidermis protects and waterproofs the stem and controls gas exchange.
- In trees, some of the epidermal tissue is replaced by bark. Bark is a combination of tissues that provides a tough, woody external covering on the stems of trees. The inner part of bark is alive and growing; the outer part is dead and provides strength, support, and protection.
- Ground tissue forms the interior of the stem. The large central vacuoles of ground tissue cells fill with water to support the plant. The cells may also store food.
- Bundles of vascular tissue run through the ground tissue of a stem and transport fluids. Plants may vary in how these bundles are arranged.

Stem Growth

The stems of all vascular plants get taller through primary growth. This occurs in primary meristem at the tips and nodes of the stems. Most stems also grow in thickness through secondary growth. This occurs in secondary meristem, which is located in and around the vascular tissues. Secondary growth forms secondary vascular tissues and bark. In many trees, the yearly growth of new vascular tissues results in an annual growth ring. (See figure) When a tree is cut down, the rings in the trunk can be counted to estimate the tree’s age.

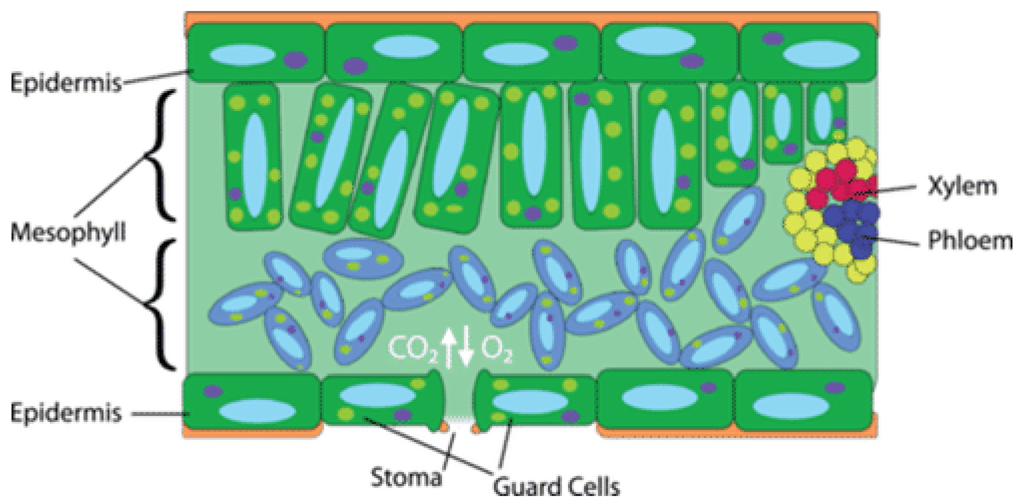
The number of rings in this cross-section of tree trunk show how many years the tree lived. What does each ring represent?

Leaves

Leaves are the keys not only to plant life but to all terrestrial life. The primary role of leaves is to collect sunlight and make food by photosynthesis. Despite the fundamental importance of the work they do, there is great diversity in the leaves of plants. However, given the diversity of habitats in which plants live, it's not surprising that there is no single best way to collect solar energy for photosynthesis.

Factories for Photosynthesis

You can think of a single leaf as a photosynthesis factory. A factory has specialized machines to produce a product. It's also connected to a transportation system that supplies it with raw materials and carries away the finished product. In all these ways, a leaf resembles a factory. The cross section of a leaf lets you look inside a leaf "factory". (See figure)

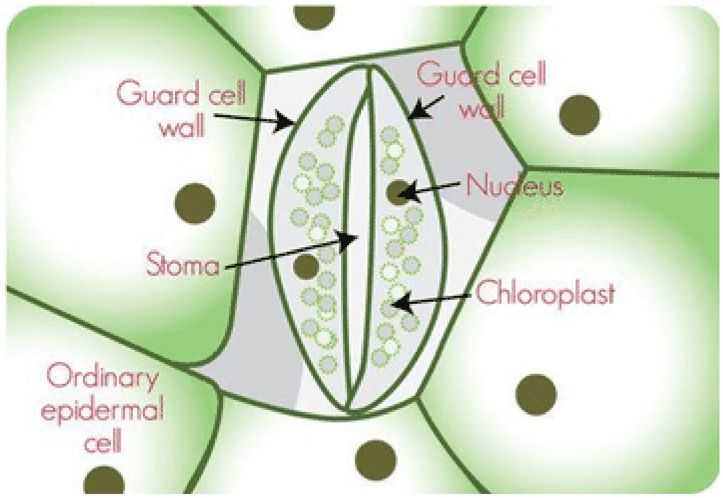


There's more to a leaf than meets the eye.

A leaf consists of several different kinds of specialized tissues that work together to make food by photosynthesis. The major tissues are mesophyll, veins, and epidermis.

- Mesophyll makes up most of the leaf's interior. This is where photosynthesis occurs. Mesophyll consists mainly of parenchyma cells with chloroplasts.
- Veins are made primarily of xylem and phloem. They transport water and minerals to the cells of leaves and carry away dissolved sugar.

- The epidermis of the leaf consists of a single layer of tightly-packed dermal cells. They secrete waxy cuticle to prevent evaporation of water from the leaf. The stomata (singular, stoma) are tiny pores found in the epidermis that control transpiration and gas exchange with the air. (See figure)



For photosynthesis, stomata must control the transpiration of water vapor and the exchange of carbon dioxide and oxygen. Stomata are flanked by guard cells that swell or shrink by taking in or losing water through osmosis. When they do, they open or close the stomata.

Flowering Plants

Angiosperms, or flowering seed plants, form seeds in ovaries. As the seeds develop, the ovaries may develop into fruits. Flowers attract pollinators, and fruits encourage animals to disperse the seeds.

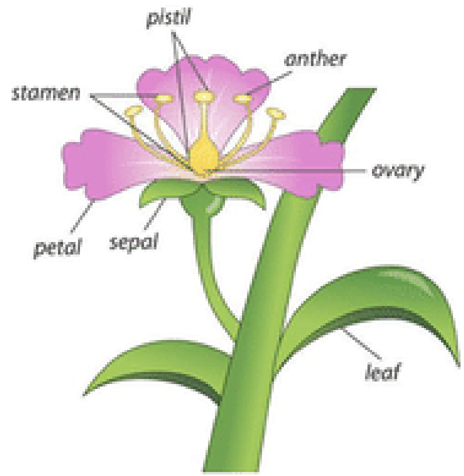
Parts of a Flower

A flower consists of male and female reproductive structures. The main parts of a flower include the stamen, pistil, petals, and sepals. (See next figure)

The stamen is the male reproductive structure of a flower. It consists of a stalk-like filament that ends in an anther. The anther contains pollen sacs, in which meiosis occurs and pollen grains form. The filament raises the anther up high so its pollen will be more likely to blow in the wind or be picked up by an animal pollinator.

The pistil is the female reproductive structure of a flower. It consists of a stigma, style, and ovary. The stigma is raised and sticky to help it catch pollen. The style supports the stigma and connects it to the ovary, which contains the egg. Petals attract pollinators to the flower. Petals are often brightly colored so pollinators will notice them.

Sepals protect the developing flower while it is still a bud. Sepals are usually green, which camouflages the bud from possible consumers.



A flower includes both male and female reproductive structures.

Summary

- Roots absorb water and minerals and transport them to stems. They also anchor and support a plant, and store food. A root system consists of primary and secondary roots. Each root is made of dermal, ground, and vascular tissues. Roots grow in length and width from primary and secondary meristem.
- Stems hold plants upright, bear leaves and other structures, and transport fluids between roots and leaves. Like roots, stems contain dermal, ground, and vascular tissues. Trees have woody stems covered with bark.
- The primary function of leaves is to collect sunlight and make food by photosynthesis. Specialized tissues in leaves work together to perform this function. In a deciduous plant, leaves seasonally turn color and fall off the plant. They are replaced with new leaves later in the year. An evergreen plant keeps its green leaves year-round. It may have needle-like leaves to reduce water loss.

Major Tissues in Plants	Function
Dermal Tissue	Compares to the skin, or epidermis in animals. Protects plant and intermediates between the plant and its environment.
Ground Tissue	Basic metabolic functions. Makes up most of the interior of the plant. Makes up most organs.
Vascular Tissue	Transports water, minerals and food throughout the plant.

Organ	Functions
Root	Anchorage Absorption of water and dissolved minerals Storage (surplus sugars transported from leaves Conduction
Stem	Conduction of water and sugars throughout plant Support leaves and fruits
Leaf	Perform photosynthesis Regulate water loss of the plant Abscission (leaf fall)
Flower	Contain reproductive organs Attract pollinators Produce fruit

Think like a Botanist

1. What are root hairs? What is their role?
2. Identify three major functions of roots.
3. What is bark? What purposes does it serve?
4. Apply lesson concepts to predict how the stem of a desert plant might be specialized for its environment.
5. Explain how a leaf is like a factory.
6. Describe two examples of how the structure of an organ is related to its function.
7. Choose an organ system and describe how it contributes to homeostasis in the body.

8. What happens when one of the systems in our bodies does not work properly and has a “system error”?

9. Pick 3 of the organ systems we studied and compile the following information:
   - The main purpose or function of the system.
   - The main processes that take place in the system.
   - The main components or organs that make up the system.

10. The main health issues related to that particular system and how it might be addressed by modern technology.

CHAPTER 4

Standard IV: Reproduction

Chapter Outline

Standard 4: Students will understand that genetic information coded in DNA is passed from parents to offspring by sexual and asexual reproduction. The basic structure of DNA is the same in all living things. Changes in DNA may alter genetic expression.

Objective 1: Compare sexual and asexual reproduction.

1. Explain the significance of meiosis and fertilization in genetic variation.
2. Compare the advantages/disadvantages of sexual and asexual reproduction to survival of species.
3. Formulate, defend, and support a perspective of a bioethical issue related to intentional or unintentional chromosomal mutations.

Objective 2: Predict and interpret patterns of inheritance in sexually reproducing organisms.

1. Explain Mendel's laws of segregation and independent assortment and their role in genetic inheritance.
2. Demonstrate possible results of recombination in sexually reproducing organisms using one or two pairs of contrasting traits in the following crosses: dominance/recessive, incomplete dominance, codominance, and sex-linked traits.
3. Relate Mendelian principles to modern-day practice of plant and animal breeding.
4. Analyze bioethical issues and consider the role of science in determining public policy.

Objective 3: Explain how the structure and replication of DNA are essential to heredity and protein synthesis.

1. Use a model to describe the structure of DNA.
2. Explain the importance of DNA replication in cell reproduction.
3. Summarize how genetic information encoded in DNA provides instructions for assembling protein molecules.
4. Describe how mutations may affect genetic expression and cite examples of mutagens.
5. Relate the historical events that lead to our present understanding of DNA to the cumulative nature of science knowledge and technology.
6. Research, report, and debate genetic technologies that may improve the quality of life (e.g., genetic engineering, cloning, gene splicing).

Unit Key Vocabulary

- Replication
- Fertilization
- Dominant Trait
- Recessive Trait
- Genetic Engineering
- Gene Splicing
- Phenotype
- Genotype
- Sexual Reproduction
- Asexual Reproduction
- Chromosome
- Gene
- Mutation
- Cloning
- Inheritance
- Bioethics
- Pedigree

4.1 Reproduction

Reproduction: One Parent or Two?

Objectives

- Compare the advantages and disadvantages of asexual and sexual reproduction.
- Explain the significance of meiosis and fertilization in genetic variation.

Reproduction: Asexual Vs. Sexual

Cell division is how organisms grow and repair themselves. It is also how many organisms produce offspring. For many single-celled organisms, reproduction is a similar process. The parent cell simply divides to form two daughter cells that are identical to the parent. In many other organisms, two parents are involved, and the offspring are not identical to the parents. In fact, each offspring is unique. Children resemble their parents, but they are not identical to them. Instead, each has a unique combination of characteristics inherited from both parents.

Family Portrait: Mother, Daughter, Father, and Son. Children resemble their parents, but they are never identical to them. Do you know why this is the case?

Reproduction is the process by which organisms give rise to offspring. It is one of the defining characteristics of living things. There are two basic types of reproduction: asexual reproduction and sexual reproduction.

Asexual Reproduction: How is this done?

Asexual reproduction (a mode of reproduction involving a single parent which results in offspring that are genetically identical to each other and to the parent) results in identical offspring called clones. Prokaryotes and some eukaryotes reproduce this way. There

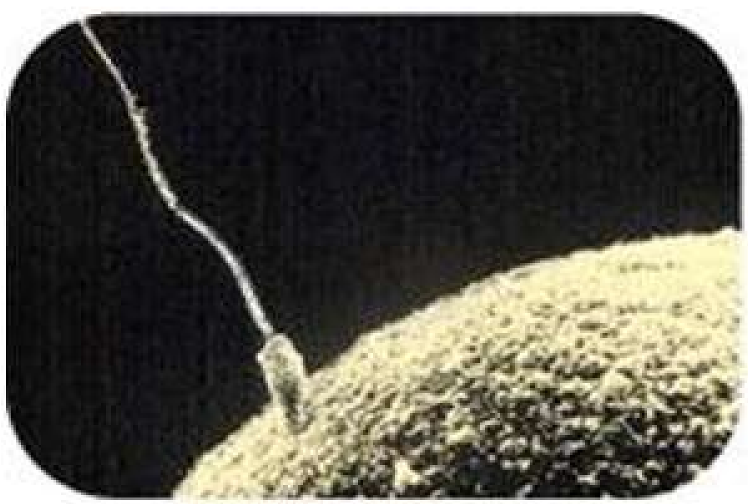
are several different methods of asexual reproduction. They include binary fission, fragmentation, and budding.

Asexual reproduction has many advantages and disadvantages. A disadvantage of asexual reproduction is that a parent passes all of its genetic material to the next generation creating no genetic variation. Without genetic variation, the population can only evolve very slowly because it depends on random mutations for evolution.

Advantages of asexual reproduction are that is only requires one parent, and it can be very rapid. This is an advantage for many organisms. It allows them to crowd out other organisms that reproduce more slowly. Bacteria, for example, may divide several times per hour. Under ideal conditions, 100 bacteria can divide to produce millions of bacterial cells in just a few hours! However, most bacteria do not live under ideal conditions. If they did, the entire surface of the planet would soon be covered with them. Instead, their reproduction is kept in check by limited resources, predators, and their own wastes. This is true of most other organisms as well.

Sexual Reproduction: Why does it take two?

Sexual reproduction (a mode of reproduction involving two parents which results in offspring that are a genetic combination of the parents), This process requires the production of reproductive cells called gametes—that unite to form an offspring. Examples of gametes are sperm, egg, pollen, and ovules. Gametes are haploid cells. This means they contain only half the number of chromosomes (strand of DNA) found in other cells (somatic cells) of the organism. Gametes are produced by a type of cell division called meiosis, which is described in detail in a subsequent concept. Fertilization (the process in which two gametes, a sperm and an egg, unite) results in a zygote. A zygote is a diploid cell, which means that it has twice the number of chromosomes as a gamete. For example, in a human somatic cell there are 46 chromosomes. Once these cells have divided by the process of meiosis, they will then have half of the genetic information becoming a gamete with only 23 chromosomes.



Fertilization of an egg cell by a sperm cell. In sexual reproduction, haploid gametes fuse to produce a diploid zygote.

Asexual Reproduction	Sexual Reproduction
Single individual is the sole parent.	Two parents give rise to offspring.
Single parent passes all genetic material to offspring.	Each parent passes on half its genetic material (genes), to its offspring.
Offspring are genetically identical to the parent.	Offspring have a unique combination of genes inherited from both parents.
Genetically identical individual. Genetic differences only occur as a result of mutations, which is a change in DNA.	Results in greater genetic variation; offspring vary genetically from their siblings and parents.
Reproduction is quick.	Reproduction is time consuming.

Do you have ALL your parents' genetic material?

Meiosis to Zygotes

A special type of cell division known as meiosis produces gametes. Meiosis contains two rounds of cell division without DNA replication in between. This process reduces the number of chromosomes by half.

Sexual reproduction creates genetic variation and requires gametes from two parents. Gametes are reproductive cells, the sperm and egg, and pollen grains and ovules which contain gametes in plants. When gametes are produced, the number of chromosomes must be reduced by half. Why? In sexual reproduction, the offspring must contain genetic information from the mother and from the father, so the gametes must contain half of the chromosomes (haploid) found in normal body cells (somatic cells). When two gametes come together at fertilization, the normal amount (diploid) of chromosomes results. The cell formed when the gametes join is called a zygote, and it contains all of the genetic material to make a new individual.

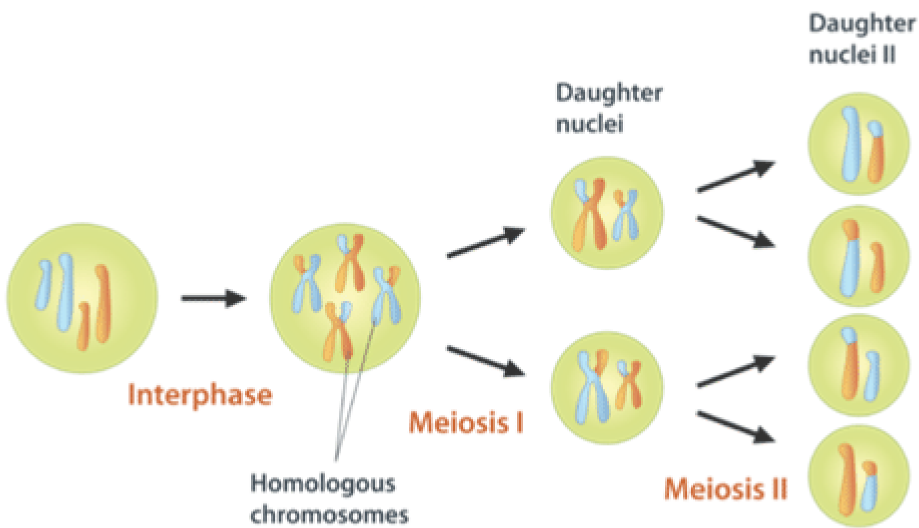
Human cells have 23 pairs of chromosomes, and each chromosome within a pair is called a homologous chromosome. For each of the 23 chromosome pairs, you received one chromosome from your father and one chromosome from your mother. So, although homologous chromosomes are very similar, they are not identical. The homologous chromosomes are separated when gametes are formed. Therefore, gametes have only 23 chromosomes, not 23 pairs.

Haploid vs. Diploid

A cell with two sets of chromosomes is diploid, referred to as 2n, where 'n' is the number of sets of chromosomes. Most of the cells in a human body are diploid. These diploid cells are referred to as somatic cells. A cell with one set of chromosomes, such as a gamete, is haploid, referred to as n. Sex cells are haploid. When a haploid sperm (n) and a haploid egg (n) combine, it is called fertilization, and a diploid zygote will be formed (2n). In short, when a diploid zygote is formed, half of the DNA comes from each parent.

The Purpose of Meiosis

Meiosis creates genetic variation and makes haploid gamete cells. Before meiosis begins, all of the DNA in the cell is copied, so each chromosome contains two identical sister chromatids. Meiosis (See figure) is divided into two divisions: Meiosis I and Meiosis II. Each division can be divided into the same phases: prophase, metaphase, anaphase, and telophase. After telophase, the cell divides into two daughter cells. Between the two cell divisions, DNA replication does not occur. Through this process, one diploid cell will divide into four haploid gamete cells.



Overview of Meiosis. During meiosis, four haploid cells are created from one diploid parent cell.

Meiosis I

Meiosis I is where the genetic variation is introduced into the daughter cells. During meiosis I, the pairs of homologous chromosomes are separated from each other. The steps are outlined below:

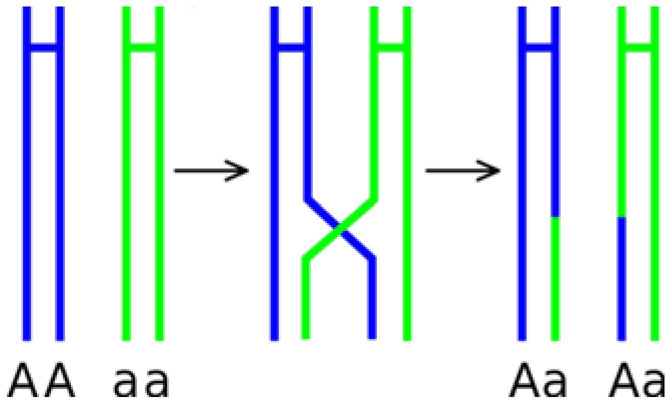
Prophase I: The homologous chromosomes line up together. During this time, a process that only happens in meiosis can occur. This process is called crossing-over (Figure below), which is the exchange of DNA between homologous chromosomes. Crossing-over forms new combinations of alleles (An allele is a gene that codes for different variations of the same trait) on the resulting chromosome, in other words it creates genetic variation. Without crossing-over, the offspring would always inherit all of the alleles on one of the homologous chromosomes. Also during prophase I, the spindle fibers form, the chromosomes condense as they coil up tightly, and the nuclear envelope disappears.

Metaphase I: The homologous chromosomes line up in their pairs in the middle of the cell. Chromosomes from the mother or from the father can each attach to either side of the spindle. Their attachment is random, so all of the chromosomes from the mother or father do not end up in the same gamete. This is called random alignment. The gamete will contain some chromosomes from the mother and some chromosomes from the father. This is the second way that meiosis creates genetic variation in the gametes.

Anaphase I: The homologous chromosomes are separated as the spindle shortens, and begin to move to opposite sides of the cell.

Telophase I: The spindle fibers dissolves, but a new nuclear envelope does not need to form. This is because, after cytokinesis, the nucleus will immediately begin to divide again. No DNA replication occurs between meiosis I and meiosis II because the chromosomes are already duplicated. After cytokinesis, two haploid cells result.

Since the separation of chromosomes into gametes is random during meiosis I, this process results in different combinations of chromosomes (and alleles) in each gamete. With 23 pairs of chromosomes, there is a possibility of over 8 million different combinations of chromosomes in a human gamete.



During crossing-over, segments of DNA are exchanged between non-sister chromatids. Notice how this can result in an allele (A) on one homologous chromosome being moved onto the other member of the pair. These new combinations of genes are one way that meiosis creates genetic variation.

Meiosis II

During meiosis II, the sister chromatids are separated and the gametes are generated. This cell division results in four genetically unique haploid gamete cells. The steps are outlined below:

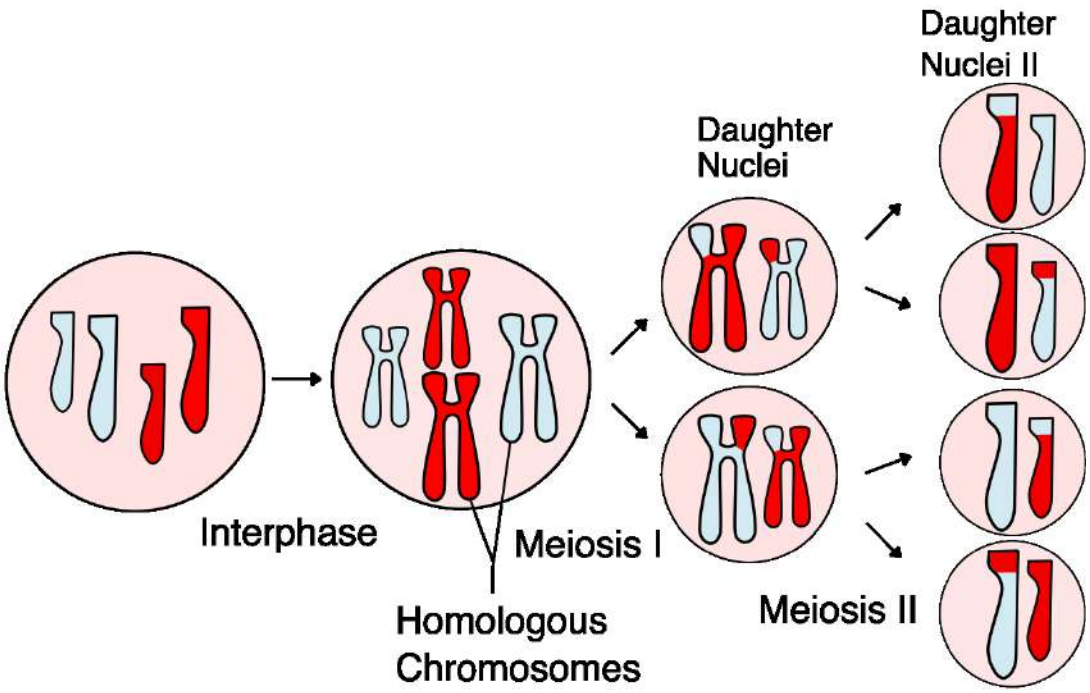
Prophase II: The chromosomes condense.

Metaphase II: The chromosomes line up one on top of each other along the middle of the cell. The spindle is attached to the centromere of each chromosome.

Anaphase II: The sister chromatids separate as the spindle shortens and move to opposite ends of the cell.

Telophase II: A nuclear envelope forms around the chromosomes in all four cells. This is followed by cytokinesis.
For an animation of this process visit http://go.uen.org/b21

Meiosis results in four haploid, genetically unique daughter cells, each with half the DNA of the parent cell (See figure). In human cells, the parent cell has 46 chromosomes, so the cells produced by meiosis have 23 chromosomes. These cells will become gametes.



An overview of meiosis.

Fertilization happens when two gametes join to form a zygote, a fertilized egg cell that contains all of the genes to make a new organism. Fertilization is an additional way that sexual reproduction increases genetic variation, because it results in the combination of genes from two separate individuals. For example, you have genes from both your father and your mother. Genetic variation is the major advantage to sexual reproduction. Increased genetic variation leads to a population with a wide variety of characteristics that can better adapt to a changing environment and evolve more rapidly. The disadvantages to sexual reproduction are that it requires more time and energy than asexual reproduction, and it involves two parents.

Summary

- Asexual reproduction produces a clone, an organism that is genetically identical to its parent.
- Sexual reproduction involves haploid gametes and produces a diploid zygote through fertilization.
- Meiosis is a process of cell division that creates genetic variation and reduces the chromosome number by half and produces sex cells, or gametes.
- Crossing-over and random alignment contribute to genetic variation among gametes.
- Four genetically unique haploid cells result from meiosis.
- Fertilization combines genes from two parents.
- There are advantages and disadvantages of both sexual and asexual reproduction.

Think like a Geneticist

1. What are the advantages and disadvantages of asexual reproduction?

2. What are the advantages and disadvantages of sexual reproduction?

3. How many chromosomes does a diploid human cell have? How many chromosomes does a haploid human gamete cell have?

4. What happens during metaphase I of meiosis? How does this compare to the metaphase of mitosis?

5. What is the resulting number of gametes after meiosis?

6. Describe the steps of Meiosis I and Meiosis II.

7. Describe crossing-over.

4.2 Inheritance Patterns

How did Mendel experiment with peas?

Objectives

- Explain Mendel's laws of segregation and independent assortment and their role in genetic inheritance.
- Predict and interpret patterns of inheritance in sexually reproducing organism.
- Distinguish between genotype and phenotype.
- Demonstrate knowledge of dominant/recessive, incomplete dominance, codominance, and sex-linked traits.

Introduction

For thousands of years, humans have understood that characteristics such as eye color or flower color are passed from one generation to the next. The inheritance of traits of passing of characteristics from parent to offspring is called heredity. Humans have long been interested in understanding heredity. Many hereditary mechanisms were developed by scholars but were not properly tested or quantified. The scientific study of genetics did not begin until the late 19th century. In experiments with garden peas, Austrian monk Gregor Mendel described the patterns of inheritance.

Gregor Johann Mendel was an Augustinian monk, a teacher, and a scientist (See next figure). He is often called the "father of modern genetics" for his study of the inheritance of traits in pea plants. Mendel showed that the inheritance of traits follows particular laws, which were later named after him. The significance of Mendel's work was not recognized until the turn of the 20th century. The rediscovery of his work laid the foundation for the era of modern genetics, the branch of biology that focuses on heredity in organisms.

Mendel was born in 1822 and grew up on his parents' farm in an area of Austria that is now in the Czech Republic. Mendel attended lectures on the growing of fruit and agriculture. His professors encouraged him to learn science through experimentation and to use mathematics to help explain observations of natural events.

Mendel’s Experiments: Why did he use peas?

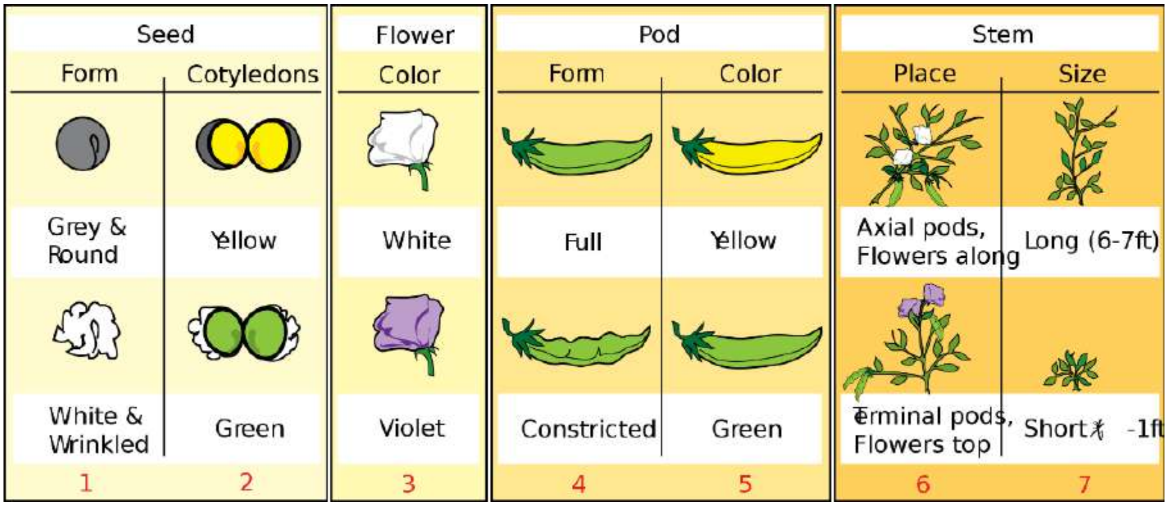
Mendel is best known for his studies of the pea plant. Mendel was inspired by both his professors at university and his colleagues at the monastery to study variation in plants. He had carried out artificial fertilization on plants many times in order to grow a plant with a new color or seed shape. Artificial fertilization is the process of transferring pollen from the male part of one flower to the female part of another flower. Artificial fertilization is done in order to have seeds that will grow into plants that have a desired trait, such as yellow flowers.

During Mendel’s time, the popular blending inheritance hypothesis stated that offspring were a “mix” of their parents. For example, if a pea plant had one short parent and one tall parent, that pea plant would be of medium height. It was believed that the offspring would then pass on heritable units, or factors, for medium sized offspring. Today we know these heritable units are genes; however, Mendel did not know of the concept of a gene. Mendel noted that plants in the monastery gardens sometimes gave rise to plants that were not exactly like the parent plants, nor were they a “mix” of the parents. He also noted that certain traits reappeared after “disappearing” in an earlier generation. Mendel was interested in finding out if there was a predictable pattern to the inheritance of traits. Between 1856 and 1863 he grew and tested about 29,000 pea plants in the monastery garden.

Mendel may have chosen to study peas because they are fast-growing plants that are available in different varieties. For example, one variety of pea plant has purple flowers, as shown in the Figure below, while another variety has white flowers.

The pea plant species that Mendel studied.

Mendel chose to study seven characteristics of pea plants. A characteristic is a heritable feature, such as flower color. Each characteristic Mendel chose to study occurred in two contrasting traits. A trait is a heritable variant of a characteristic, such as purple or white flower color. Table below lists the seven characteristics Mendel studied, and their two contrasting traits.



Peas. Some round and some wrinkled. Why?

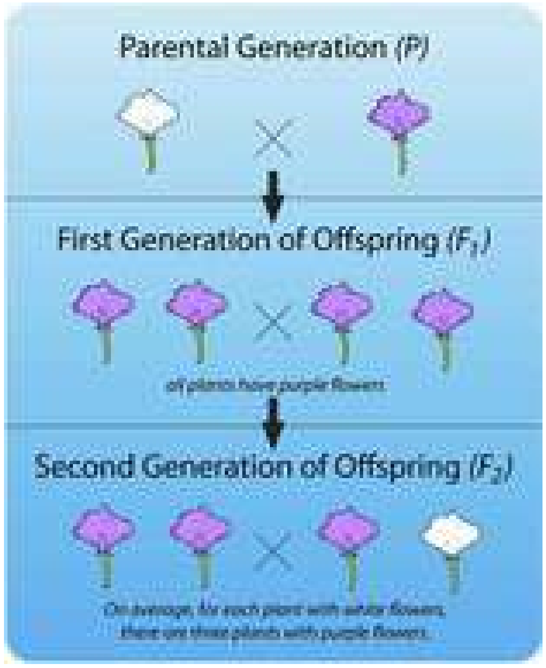
That's what Mendel asked. He noticed peas were always round or wrinkled, but never anything else. Seed shape was one of the traits Mendel studied in his first set of experiments.

Mendel's First Set of Experiments

Mendel first experimented with just one characteristic of a pea plant at a time. He began with flower color. As shown in the Figure below, Mendel cross-pollinated purple- and white-flowered parent plants. The parent plants in the experiments are referred to as the P (for parent) generation.

You can explore an interactive animation of Mendel's first set of experiments at this link:

- http://go.uen.org/b23



This diagram shows Mendel’s first experiment with pea plants. The F1 generation results from cross-pollination of two parent (P) plants. The F2 generation results from self-pollination of F1 plants.

F1 and F2 Generations

The offspring of the P generation are called the F1 (for filial, or “offspring”) generation. As you can see from Figure above, all of the plants in the F1 generation had purple flowers. None of them had white flowers. Mendel wondered what had happened to the white-flower characteristic. He assumed some type of inherited factor produces white flowers and some other inherited factor produces purple flowers. Did the white-flower factor just disappear in the F1 generation? If so, then the offspring of the F1 generation—called the F2 generation—should all have purple flowers like their parents.

To test this prediction, Mendel allowed the F1 generation plants to self-pollinate. He was surprised by the results. Some of the F2 generation plants had white flowers. He studied hundreds of F2 generation plants, and for every three purple-flowered plants, there was an average of one white-flowered plant.

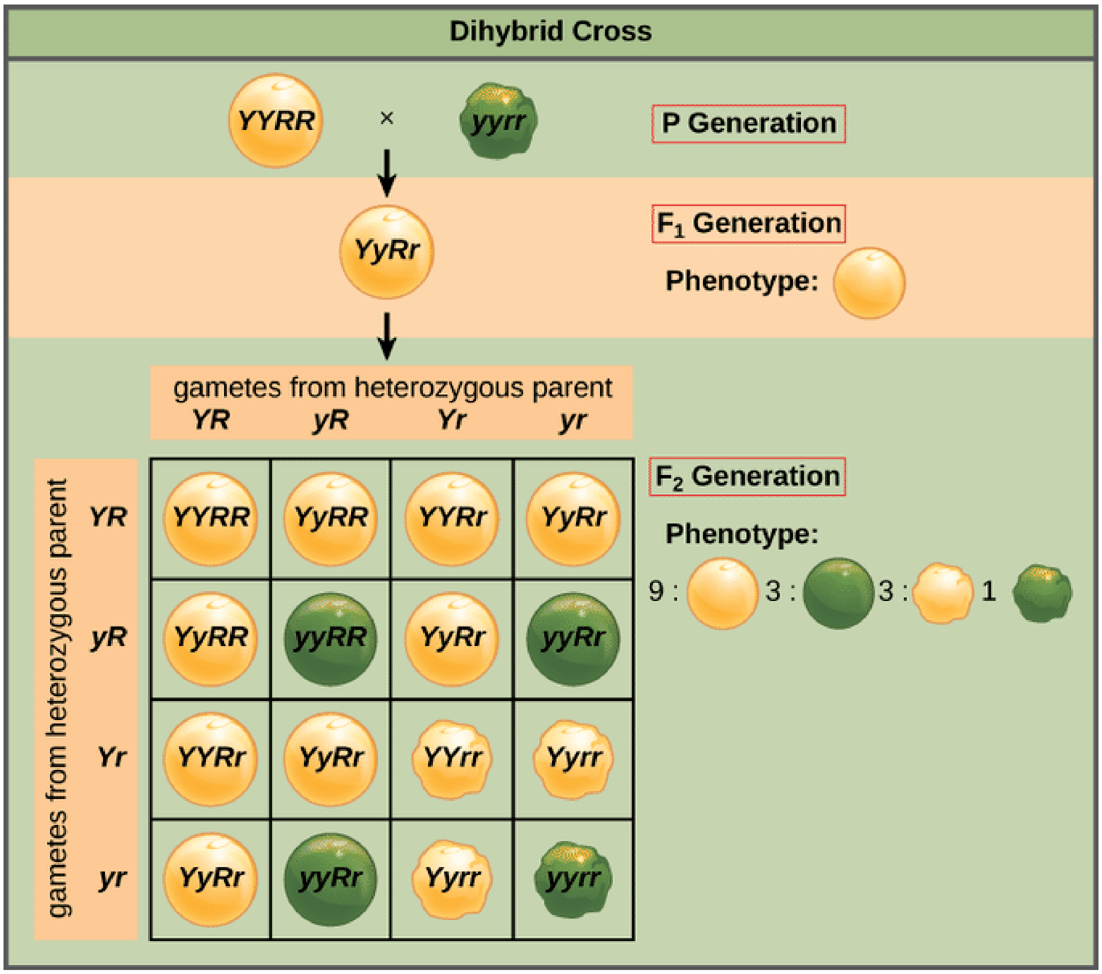
Law of Segregation

Mendel did the same experiment for all seven characteristics. In each case, one value of the characteristic disappeared in the F1 plants and then showed up again in the F2 plants. And in each case, approximately 75 percent of F2 plants had one value of the characteristic and approximately 25 percent had the other value. Based on these observations, Mendel formulated his first law of inheritance. This law is called the law of segregation. It states that there are two factors controlling a given characteristic, one

of which dominates the other, and these factors separate and go to different gametes when a parent reproduces.

Mendel's Second Set of Experiments

After observing the results of his first set of experiments, Mendel wondered whether different characteristics are inherited together. For example, are purple flowers and tall stems always inherited together? Or do these two characteristics show up in different combinations in offspring? To answer these questions, Mendel next investigated two characteristics at a time. For example, he crossed plants with yellow round seeds and plants with green wrinkled seeds. The results of this cross are called a dihybrid cross.



This chart represents Mendel's second set of experiments. It shows the outcome of a cross between plants that differ in seed color (yellow or green) and seed form (shown here with a smooth round appearance or wrinkled appearance). The letters R, r, Y, and y represent genes for the characteristics Mendel was studying. Mendel didn't know about genes, however. Genes would not be discovered until several decades later. This experiment demonstrates that 9/16 were round yellow, 3/16 were wrinkled yellow, 3/16 were round green, and 1/16 were wrinkled green.

F1 and F2 Generations

In this set of experiments, Mendel observed that plants in the F1 generation were all alike. All of them had yellow and round seeds like one of the two parents. When the F1 generation plants self-pollinated, however, their offspring—the F2 generation—showed all possible combinations of the two characteristics. Some had green round seeds, for example, and some had yellow wrinkled seeds. These combinations of characteristics were not present in the F1 or P generations.

Law of Independent Assortment

Mendel repeated this experiment with other combinations of characteristics, such as flower color and stem length. Each time, the results were the same as those in the Figure below. The results of Mendel's second set of experiments led to his second law. This is the law of independent assortment. It states that factors controlling different characteristics are inherited independently of each other.

What's the chance of the coin landing on heads?

There is always a 50-50 chance that a coin will land on heads. Half the time it will land on heads and half the time it will land on tails. These rules of probability also apply to genetics. If a parent has one dominant and one recessive factor for a trait, then half the time the dominant factor will be passed on, and half the time the recessive factor will be passed on.

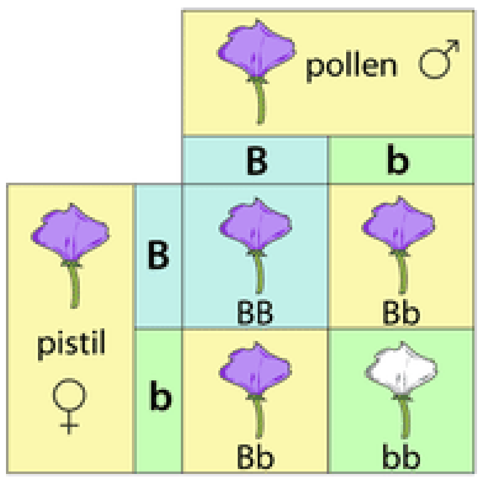
Linked Genes on Chromosomes

We now know that the only alleles that are inherited independently are ones that are located far apart on a chromosome or that are on different chromosomes. There are many genes that are close together on a chromosome, and are packaged into the gametes together. Genes that are inherited in this way are called linked genes. Linked genes tend to be inherited together because they are located on the same chromosome.

Genetic linkage was first discovered by the British geneticists William Bateson and Reginald Punnett shortly after Mendel's laws were rediscovered.

Punnett Squares: Where do your genes come from?

A Punnett square is a chart that allows you to easily determine the expected percentage of different genotypes in the offspring of two parents. An example of a Punnett square for pea plants is shown in the Figure below. In this example, both parents are heterozygous for flower color (Bb). Heterozygous means that there is one dominant allele and one recessive allele. A dominant allele shows up ¾ of the time. A recessive allele shows up ¼ of the time. Homozygous means that the alleles are the same; either both are dominant or both are recessive. The gametes produced by the male parent are at the top of the chart, and the gametes produced by the female parent are along the side. The different possible combinations of alleles in their offspring are determined by filling in the cells of the Punnett square with the correct letters (alleles).



Punnett Square. This Punnett square shows a cross between two heterozygotes. Do you know where each letter (allele) in all four cells comes from?

An example of the use of a Punnett square can be viewed at:

- http://go.uen.org/b24

Predicting Offspring Genotypes and Phenotypes

A person's genotype are the genes that they inherit from each parent. Genotypes are represented by letters; one letter for each gene. A phenotype is the physical expression of the genotype. An example of a phenotype would be eye color. In the cross shown in the Figure above, you can see that one out of four offspring (25 percent) has the genotype BB, (homozygous dominant) one out of four (25 percent) has the genotype bb, (homozygous recessive) and two out of four (50 percent) have the genotype Bb, (heterozygous). These percentages of genotypes are what you would expect in any cross between two heterozygous parents. Of course, when just four offspring are produced, the actual percentages of genotypes may vary by chance from the expected

percentages. However, if you considered hundreds of such crosses and thousands of offspring, you would get very close to the expected results, just like tossing a coin.

Predicting Offspring Phenotypes

You can predict the percentages of phenotypes in the offspring of this cross from their genotypes. B is dominant to b, so offspring with either the BB or Bb genotype will have the purple-flower phenotype. Only offspring with the bb genotype will have the white-flower phenotype. Therefore, in this cross, you would expect three out of four (75 percent) of the offspring to have purple flowers and one out of four (25 percent) to have white flowers. These are the same percentages that Mendel got in his first experiment.

Determining Missing Genotypes

A Punnett square can also be used to determine a missing genotype based on the other genotypes involved in a cross. Suppose you have a parent plant with purple flowers and a parent plant with white flowers. Because the b allele is recessive, you know that the white-flowered parent must have the genotype bb. The purple-flowered parent, on the other hand, could have either the BB or the Bb genotype. The Punnett square in the Figure below shows this cross. The question marks (?) in the chart could be either B or b alleles.

White Flowered Parent

Purple Flowered Parent	Parents	b	b
	B	Bb	Bb
	?	?b	?b

Punnett Square: Cross Between White-Flowered and Purple-Flowered Pea Plants. This Punnett square shows a cross between a white-flowered pea plant and a purple-flowered pea plant. Can you fill in the missing alleles? What do you need to know about the offspring to complete their genotypes?

Can you tell what the genotype of the purple-flowered parent is from the information in the Punnett square? No; you also need to know the genotypes of the offspring in row 2. What if you found out that two of the four offspring have white flowers? Now you know that the offspring in the second row must have the bb genotype. One of their b alleles obviously comes from the white-flowered (bb) parent, because that's the only allele this parent has. The other b allele must come from the purple-flowered parent. Therefore, the parent with purple flowers must have the genotype Bb.

Punnett Square for Two Characteristics

When you consider more than one characteristic at a time, using a Punnett square is more complicated. This is because many more combinations of alleles are possible. For example, with two genes each having two alleles, an individual has four alleles, and these four alleles can occur in 16 different combinations.

Dominant and Recessive Alleles

Mendel used letters to represent dominant and recessive factors. Likewise, geneticists now use letters to represent alleles. Capital letters refer to dominant alleles, and lowercase letters refer to recessive alleles. For example, the dominant allele for the trait of green pod color is indicated by G. The recessive trait of yellow pod color is indicated by g. A true-breeding plant for green pod color would have identical alleles GG in all its somatic cells. Likewise, a true-breeding plant for yellow pod color would have identical alleles gg in all of its somatic cells. During gamete formation, each gamete receives one copy of an allele. When fertilization occurs between these plants, the offspring receives two copies of the allele, one from each parent. In this case, all of the offspring would have two different alleles, Gg, one from each of its parents.

An organism that has an identical pair of alleles for a trait is called homozygous. The true-breeding parents GG and gg are homozygous for the pod color gene. Organisms that have two different alleles for a gene are called heterozygous. The offspring of the cross between the GG and gg plants are all heterozygous for the pod color gene. Due to the dominant and recessive nature of alleles, an organism’s traits do not always reveal its genetics. Therefore, geneticists distinguish between an organism’s genetic makeup, called its genotype, and its physical traits, called its phenotype. For example, the GG parent and the Gg offspring have the same phenotype (green pods) but different genotypes.

Albinism is a recessively inherited disorder in which the body does not produce enough of the pigment melanin. The skin, hair, and eyes of a person with albinism appear white or pale.

Summary

- Genetics is the branch of biology that focuses on heredity in organisms.
- Modern genetics is based on Mendel's explanation of how traits are passed from generation to generation.
- For each of the seven characteristics Mendel studied, he observed a similar ratio in the inheritance of dominant to recessive traits (3:1) in the F2 generation.
- Mendel developed a theory that explained simple patterns of inheritance in which two alleles are inherited to result in one of several traits in offspring.
- The law of segregation states that a pair of alleles is segregated during the formation of gametes and that each gamete has an equal chance of getting either one of the allele.
- The law of independent assortment states that the inheritance of one trait will not affect the inheritance of another. That is, genes are inherited independently of each other.
- Mendelian inheritance patterns can be seen in humans. Albinism is a genetic disorder that is inherited as a simple Mendelian trait.
- Genotype determines phenotype. A homozygous dominant or a heterozygous genotype will always show a dominant phenotype. A homozygous recessive genotype can only show a recessive phenotype.
- A Punnett square is a chart that allows you to determine the expected percentages of different genotypes in the offspring of two parents.
- A Punnett square allows the prediction of the percentages of phenotypes in the offspring of a cross from known genotypes.

Online Interactives/Simulations

Part Two of Interactive Game on Meiosis and Genetics (Diversity and Dihybrid Crosses):

- http://go.uen.org/b25

Think like an Austrian Monk

1. What did Gregor Mendel contribute to the science of genetics?

2. Identify the relationship between genes and alleles.

3. Summarize the law of segregation.

4. Summarize the law of independent assortment.

5. Relate the term homozygous to heterozygous by using an example from Mendel’s experiments.

6. Relate the term genotype to phenotype by using an example from Mendel’s experiments.

7. Why can’t you always identify the genotype of an organism from its phenotype?

8. Do you think all inheritance is as straightforward as the inheritance in pea plants? Explain.

9. Is there a relationship between inheritance and probability? What might that relationship be?

Ethical, Legal and Social Issues: Right or Wrong?

Imagine someone analyzes part of your DNA. Who controls that information? What if your health insurance company found out you were predisposed to develop a devastating genetic disease? Might they decide to cancel your insurance? Privacy issues concerning genetic information is an important issue in this day and age.

ELSI stands for Ethical, Legal and Social Issues. It's a term associated with the Human Genome project. This project didn't only have the goal to identify all the genes in the human genome, but also to address the ELSI that might arise from the project. Rapid advances in DNA-based research, human genetics, and their applications have resulted in new and complex ethical and legal issues for society.

Concerns from Biotechnology

The use of biotechnology has raised a number of ethical, legal, and social issues. Here are just a few:

- Who owns genetically modified organisms such as bacteria? Can such organisms be patented like inventions?
- Are genetically modified foods safe to eat? Might they have unknown harmful effects on the people who consume them?
- Are genetically engineered crops safe for the environment? Might they harm other organisms or even entire ecosystems?
- Who controls a person's genetic information? What safeguards ensure that the information is kept private?
- How far should we go to ensure that children are free of mutations? Should a pregnancy be ended if the fetus has a mutation for a serious genetic disorder?

Addressing such issues is beyond the scope of this concept. The following example shows how complex the issues may be:

A strain of corn has been created with a gene that encodes a natural pesticide. On the positive side, the transgenic corn is not eaten by insects, so there is more corn for people to eat. The corn also doesn't need to be sprayed with chemical pesticides, which can harm people and other living things. On the negative side, the transgenic corn has been shown to cross-pollinate nearby milkweed plants. Offspring of the cross-pollinated milkweed plants are now known to be toxic to monarch butterfly caterpillars that depend on them for food. Scientists are concerned that this may threaten the monarch species as well as other species that normally eat monarchs.

As this example shows, the pros of biotechnology may be obvious, but the cons may not be known until it is too late. Unforeseen harm may be done to people, other species, and entire ecosystems. No doubt the ethical, legal, and social issues raised by biotechnology will be debated for decades to come.

Summary

- Biotechnology has raised a number of ethical, legal, and social issues. For example, are genetically modified foods safe to eat, and who controls a person's genetic information?

Think like a Geneticist

1. What are two concerns associated with biotechnology?

2. Why could genetically engineered plants replace naturally grown plants?

3. What is cloning? What was the first cloned large mammal?

4. What are two ethical considerations associated with the human genome sequence?

5. Identify an ethical, legal, or social issue raised by biotechnology. State your view on the issue, and develop a logical argument to support your view.

4.3 Mendelian Genetics

Mendelian Genetics

Objectives

- Relate Mendelian principles to modern day practice of plant and animal breeding.
- Demonstrate possible results of recombination in sexually reproducing organisms using one or two pair of contrasting traits in the following crosses; incomplete dominance, codominance, and sex-linked traits.
- Examine how a pedigree is used in the study of human inheritance.
- Describe how incomplete dominance does not follow Mendelian Inheritance.

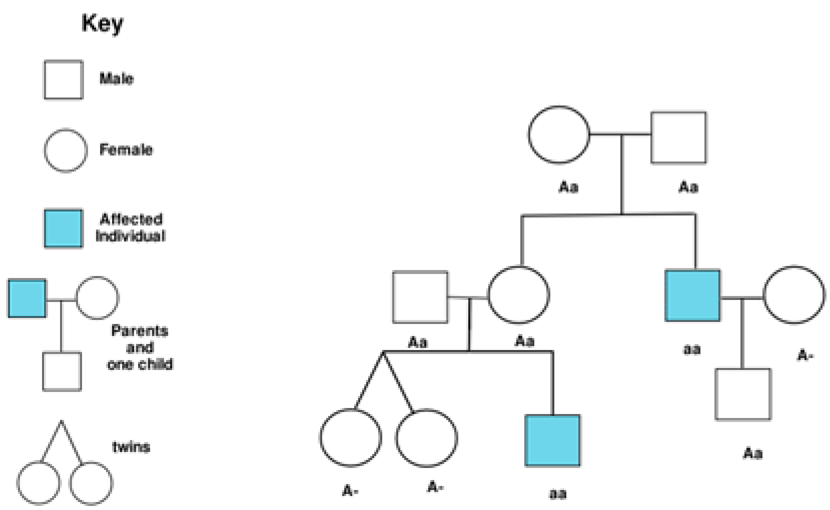
Introduction

A Mendelian trait is a trait that is controlled by a single gene that has two alleles. One of these alleles is dominant (more commonly expressed) and the other is recessive (less commonly expressed). We learned about these simple traits in the previous section. Several inheritable conditions in humans are passed to offspring in a simple Mendelian fashion. Medical professionals use Mendel's laws to predict and understand the inheritance of certain traits in their patients. Also, farmers, animal breeders, and horticulturists who breed organisms can predict outcomes of crosses by understanding Mendelian inheritance.

Farmers and breeders use Mendelian genetics daily in order to determine which traits they want to be passed to the next generation. For example, heirloom tomato farmers will choose the tomatoes with the best taste to plant seeds for the next generation. They operate under the assumption that the best tasting tomatoes have certain genes that will be passed on, making the next generation of tomatoes even better tasting. Heirloom tomatoes are chosen for their taste, not their looks, so they don't look like the tomatoes sold in regular grocery stores. The grocery store tomatoes are bred to be larger and to withstand transportation from the farm to the store.

Mendelian Inheritance in Humans: What is a pedigree?

A pedigree is a chart that shows the inheritance of a trait over several generations. A pedigree is commonly created for families, and it outlines the inheritance patterns of genetic disorders. The figure below shows a pedigree depicting recessive inheritance of a disorder through three generations. Scientists can tell the genetics of inheritance from studying a pedigree, such as whether the trait is sex-linked (on the X or Y chromosome) or autosomal (on a chromosome that does not determine sex), whether the trait is inherited in a dominant or recessive fashion, and possibly whether individuals with the trait are heterozygous or homozygous.



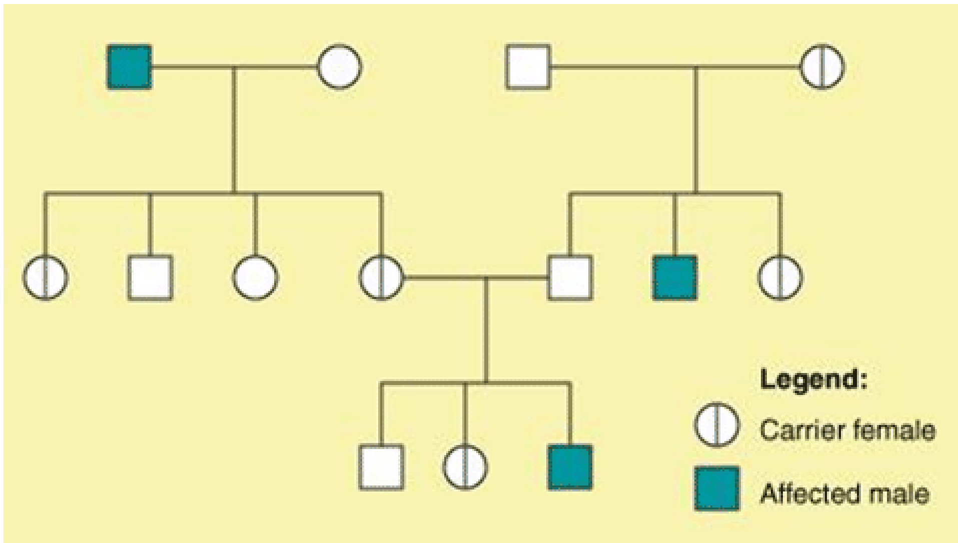
In a pedigree, squares symbolize males, and circles represent females. A horizontal line joining a male and female indicates that the couple had offspring. Vertical lines indicate offspring that are listed left to right, in order of birth. Shading of the circle or square indicates an individual who has the trait being traced. The inheritance of the recessive trait is being traced. Capital “A” is the dominant allele and “lower case” “a” is recessive.

Is the trait sex-linked or autosomal? A sex chromosome is a chromosome that determines the sex of an organism. Humans have two sex chromosomes, X and Y. Females have two X chromosomes (XX), and males have one X and one Y (XY). An autosome is any chromosome other than a sex chromosome. If a trait is autosomal it will affect males and females equally.

A sex-linked trait is a trait whose allele is found on a sex chromosome. The human X chromosome is significantly larger than the Y chromosome; there are many more genes located on the X chromosome than there are on the Y chromosome. As a result there are many more X-linked traits than there are Y-linked traits. Most sex-linked traits are recessive. Because males carry only one X chromosome, if they inherit a recessive sex-

linked gene they will show a sex-linked condition, and these types of conditions are much more common in men than women.

Because of the recessive nature of most sex-linked traits, a female who shows a sex-linked condition would have to have two copies of the sex-linked allele, one on each of her X chromosomes. The figure below shows how red-green colorblindness, a sex-linked disorder, is passed from parent to offspring.



An X-linked disorder such as red-green colorblindness is normally passed on to the son of a carrier mother. Usually, females are unaffected as they have a second, normal copy of the allele on the second X chromosome. However, if a female inherits two defective copies of the allele, she will be colorblind. Therefore, every son of a colorblind woman will be colorblind.

Extension Resource for Sex-linked Traits:

- http://go.uen.org/b26

Pedigree analysis can be used to find out whether a trait is sex-linked, dominant or recessive, and whether individuals have the homozygous or heterozygous phenotype.

Is the Trait Dominant or Recessive?

If a trait is autosomal dominant, every person with the trait will have a parent with the trait. If the trait is recessive, a person with the trait may have one, both or neither parent with the trait. An example of an autosomal dominant disorder in humans is Huntington's disease (HD). Huntington's disease is a degenerative disease of the nervous system. It has no obvious effect on phenotype until the person is aged 35 to 45 years old. The disease is incurable and, eventually, fatal. Every child born to a person who develops HD has a 50% chance of inheriting the defective allele from the parent.

Are the Individuals with the Trait Heterozygous or Homozygous?

If a person shows the dominant phenotype, they could be either homozygous dominant (AA) or heterozygous (Aa). A person who is heterozygous (Aa) is called a carrier because they carry a copy of the recessive allele even though they don't have the disease because of the presence of a dominant allele. Only people who are homozygous for a recessive allele of a trait will have the trait.

Non-Mendelian Modes of Inheritance

The relationship between genotype and phenotype is rarely as simple as the examples Mendel studied. Each characteristic he studied had two alleles, one of which was completely dominant and the other completely recessive. Geneticists now know that alleles can be also be codominant and incompletely dominant.

Codominance

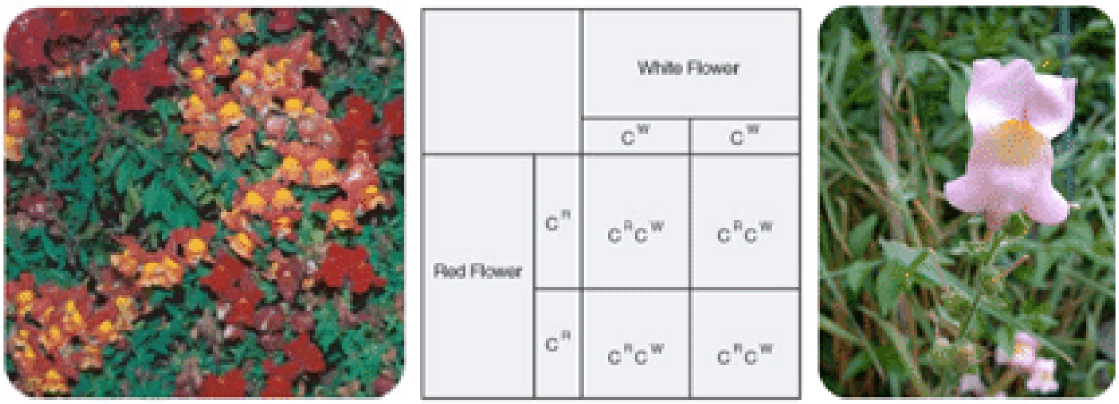
Codominance occurs when both traits appear in a heterozygous offspring. Neither allele is completely dominant nor completely recessive. For example, roan shorthorn cattle have codominant genes for hair color. The coat has both red and white hairs. The letter R indicates red hair color, and R' white hair color. In cases of codominance, the genotype of the organism can be determined from its phenotype. The heifer in the figure on the following page is RR' heterozygous for coat color.

The roan coat of this shorthorn heifer is made up of red and white hairs. Both the red and white hair alleles are codominant. Therefore cattle with a roan coat are heterozygous for coat color (RR).

Incomplete Dominance

Incomplete dominance occurs when the phenotype of the offspring is somewhere in between the phenotypes of both parents; a completely dominant allele does not occur.

This is a mixing of both genes. Think of mixing white paint with red paint and getting pink paint. For example, when red snapdragons (CRCR) are crossed with white snapdragons (CWCW), the F1 hybrids are all pink heterozygotes for flower color (CRCW). The pink color is an intermediate between the two parent colors. When two F1 (CRCW) hybrids are crossed they will produce red, pink, and white flowers. The genotype of an organism with incomplete dominance can be determined from its phenotype (Figure below).



Snapdragons show incomplete dominance in the traits for flower color. The offspring of homozygous red-flowered and homozygous white-flowered parents are heterozygous pink-flowered.

Polygenic Traits

Are all people either short or tall?

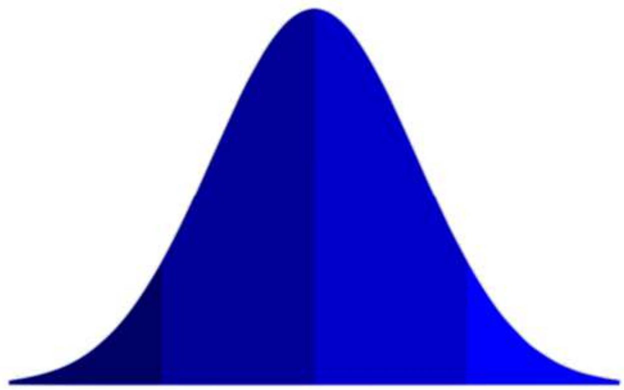
Unlike Mendel's peas, people do not all fall into two categories: short or tall. Most people, in fact, are somewhere in between. Obviously, Mendel's rules are too simple to explain the inheritance of human height.

Polygenic Traits

Another exception to Mendel’s rules is **polygenic inheritance**, which occurs when a trait is controlled by more than one gene. This means that each dominant allele "adds" to the expression of the next dominant allele.

Usually, traits are polygenic when there is wide variation in the trait. For example, humans can be many different sizes. Height is a **polygenic trait**, controlled by at least three genes with six alleles. If you are dominant for all of the alleles for height, then you will be very tall. There is also a wide range of skin color across people. Skin color is also a polygenic trait, as are hair and eye color.

Polygenic inheritance often results in a bell shaped curve when you analyze the population. That means that most people fall in the middle of the phenotypic range, such as average height, while very few people are at the extremes, such as very tall or very short. At one end of the curve will be individuals who are recessive for all the alleles (for example, *aabbcc*); at the other end will be individuals who are dominant for all the alleles (for example, *AABBCC*). Through the middle of the curve will be individuals who have a combination of dominant and recessive alleles (for example, *AaBbCc* or *AaBBcc*).



Polygenic traits tend to result in a distribution that resembles a bell-shaped curve, with few at the extremes and most in the middle. There may be 4 or 6 or more alleles involved in the phenotype. At the left extreme, individuals are completely dominant for all alleles, and at the right extreme, individuals are completely recessive for all alleles. Individuals in the middle have various combinations of recessive and dominant alleles.

Summary

- A pedigree can help geneticists discover if a trait is sex-linked, if it is dominant or recessive, and if the person (or people) who have the trait are homozygous or heterozygous for that trait.
- The Mendelian pattern of inheritance and expression does not apply to all traits. Codominant traits, incompletely dominant traits, do not follow simple Mendelian patterns of inheritance. Their inheritance patterns are more complex.
- In polygenic inheritance, a trait is controlled by more than one gene. Examples of polygenic inheritance include height or skin color.

Practice

Draw the Punnett Square to show the inheritance for color blindness if a carrier female reproduces with a normal male. Approximately what percentage of their daughters will be colorblind? Carriers? What about their sons?

Think like a Geneticist

1. How do Punnett squares help in predicting the probability a trait will be seen?
2. What do the capital letters in a Genotype tell us about a trait? (ex. PP)
3. Mendel carried out a monohybrid cross to examine the inheritance of the characteristic for seed color. The dominant allele for yellow seed color is Y, and the recessive allele for green color is y. The two plants that were crossed were F1 monohybrid Yy. Draw a Punnett square to identify the ratios of traits that Mendel observed in the F2 generation.
4. Write the different genotypes of the above problem and write what ratio you would find them. (ex. YY=1/4)
5. Mendel carried out a monohybrid cross to examine the inheritance of the characteristic for seed shape. The dominant allele for round seeds is R, and the recessive allele for a wrinkled shape is r. The two plants that were crossed were F1 monohybrid Rr. Draw a Punnett square to identify the ratios of traits that Mendel observed in the F2 generation.
6. Write the ratio of Phenotypes that you will get with the above Punnett square. (RR = round)
7. Draw a pedigree that illustrates the passing of the dominant cleft chin trait through three generations. A person who has two recessive alleles does not have a cleft chin. Let us say that C is the dominant allele, c is the recessive allele.
8. A classmate tells you that a person can have type AO blood. Do you agree? Explain.
9. Mendelian inheritance does not apply to the inheritance of alleles that result in incomplete dominance and codominance. Explain why this is so.
10. How can breeding tomato plants create a better product to sell?
11. Explain codominance and give an example.
12. What is incomplete dominance?
13. A sex linked gene is located on which chromosome, X or Y?
14. If a son was colorblind but both parents were not color blind, what would be the genotype of his parents?
15. What would be the genotypes of the parents of a colorblind daughter?

4.4 DNA

Objectives

- Explain how the structure and replication of DNA are essential to heredity and protein synthesis.
- Discuss how the work of Griffith, Avery, Hershey, and Chase demonstrated that DNA is the genetic material.
- Discuss the findings of Chargaff. Describe the importance of the finding that in DNA, the amount of adenine and thymine were about the same and that the amount of guanine and cytosine were about the same. This finding lead to the base pairing rules.
- Explain Watson and Crick's double helix model of DNA.
- Describe the structure of DNA.
- Describe how DNA is replicated, transcribed, and translated, and how that is important in cell reproduction.
- Describe how mutations may affect genetic expression and cite examples of mutagens.

Is my DNA the Same as My Mother's?

Introduction

What tells the first cell of an organism what to do? How does that first cell know to become two cells, then four cells, and so on? Does this cell have instructions? What are those instructions and what do they really do? What happens when those instructions don't work properly? Are the "instructions" the genetic material? Though today it seems completely obvious that Deoxyribonucleic acid, or DNA, is the genetic material, this was not always known.

DNA and RNA

Practically everything a cell does, be it a liver cell, a skin cell, or a bone cell, it does because of proteins. It is your proteins that make a bone cell act like a bone cell, a liver cell act like a liver cell, or a skin cell act like a skin cell. In other words, it is the proteins that give an organism its traits. We know that it is your proteins that make you tall or short, have light or dark skin, or have brown or blue eyes. But what tells those proteins how to act? It is the structure of the protein that determines what it does. And it is the order and type of amino acids that determine the structure of the protein. And that order

and type of amino acids that make up the protein are determined by your DNA sequence.

The relatively large chromosomes that never leave the nucleus are made of DNA. And, as proteins are made on the ribosomes in the cytoplasm, how does the information encoded in the DNA get to the site of protein synthesis? That's where RNA comes into this four-player act.

$$\text{DNA} \rightarrow \text{RNA} \rightarrow \text{Protein}$$

This is known as the central dogma of molecular biology. It states "DNA makes RNA which makes protein". This process starts with DNA. First, DNA had to be identified as the genetic material.

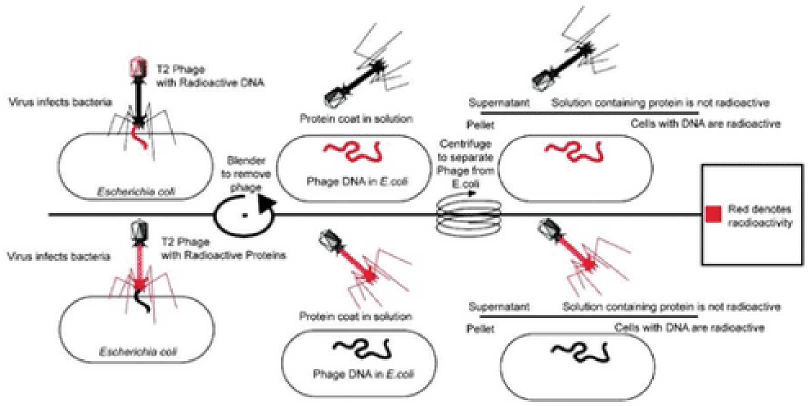
The Hereditary Material

For almost 100 years, scientists have known plenty about proteins. They have known that proteins of all different shapes, sizes, and functions exist. For this reason, many scientists believed that proteins were the hereditary material. It wasn't until 1928, when Frederick Griffith identified the process of transformation, that individuals started to question this concept. Griffith demonstrated that transformation occurs, but couldn't identify the transforming substance. The transforming substance must be the genetic material!

Over the next decade, scientists, led by Oswald Avery, tried to identify the material involved in transformation. Avery, together with his colleagues Maclyn McCarty and Colin MacLeod, performed many experiments. They discovered that DNA was the hereditary material In 1944.

This finding was not widely accepted, partly because so little was known about DNA. It was still thought that proteins were better candidates to be the hereditary material. The structure of DNA was still unknown, and many scientists were not convinced that genes from bacteria and more complex organisms could be similar.

In 1952, Alfred Hershey and Martha Chase put this skepticism to rest. They conclusively demonstrated that DNA is the genetic material that is passed from a parent to an offspring. Hershey and Chase used a virus that infects bacteria, to prove this point. A virus is essentially DNA (or RNA) surrounded by a protein coat (See figure). To reproduce, a virus must infect a cell and use that host cell's machinery to make more viruses.



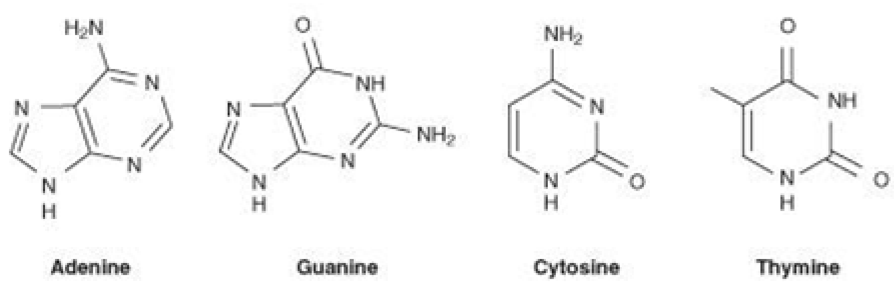
Structural overview of T2 phage. A 2-dimensional representation is on the left, and a 3-dimensional representation is on the right. The phage is essentially nucleic acid (DNA) surrounded by a protein coat.

Hershey and Chase performed a series of classic experiments, taking advantage of the fact that a virus is essentially just DNA and protein. In the experiments, a virus with either radioactive DNA or radioactive protein were used to infect bacteria. Either the radioactive proteins or radioactive DNA would be transferred to the bacteria. Identifying which one is transferred would identify the genetic material. Only the radioactively labeled DNA was found inside the bacteria. These experiments demonstrated that DNA is the genetic material and that protein does not transmit genetic information.

The Hershey and Chase experiment. T2 virus with either radioactive DNA (upper section) or radioactive protein (lower section) were used to infect bacteria. A blender was used to remove the phage from the bacteria followed by centrifugation. The radioactive DNA was found inside the bacteria (upper section), demonstrating that DNA is the genetic material.

Chargaff's Rules

It was known that DNA is composed of nucleotides, each of which contains a nitrogen-containing base, a five-carbon sugar (deoxyribose), and a phosphate group. In these nucleotides, there is one of the four possible bases: adenine (A), guanine (G), cytosine (C), or thymine (T) (see the next figure).



Chemical structure of the four nitrogenous bases in DNA.

Erwin Chargaff proposed two main rules that have been appropriately named Chargaff's rules. 1st: In 1947 he showed that the composition of DNA varied from one species to another. This molecular diversity added evidence that DNA could be the genetic material. 2nd: Chargaff also determined that in DNA, the amount of one base always approximately equals the amount of a particular second base. For example, the number of guanines equals the number of cytosines, and the number of adenines equals the number of thymines. Human DNA is 30.9% A and 29.4% T, 19.9% G and 19.8% C. This finding, together with that of the DNA structure, led to the base-pairing rules of DNA. Adenine and guanine are known as purines. These bases consist of two ring structures. Purines make up one of the two groups of nitrogenous bases. Thymine and cytosine are pyrimidines, which have just one ring structure. By having a purine always combine with a pyrimidine in the DNA double helix, the distance between the two sugar-phosphate backbones is constant, maintaining the uniform shape of the DNA molecule.

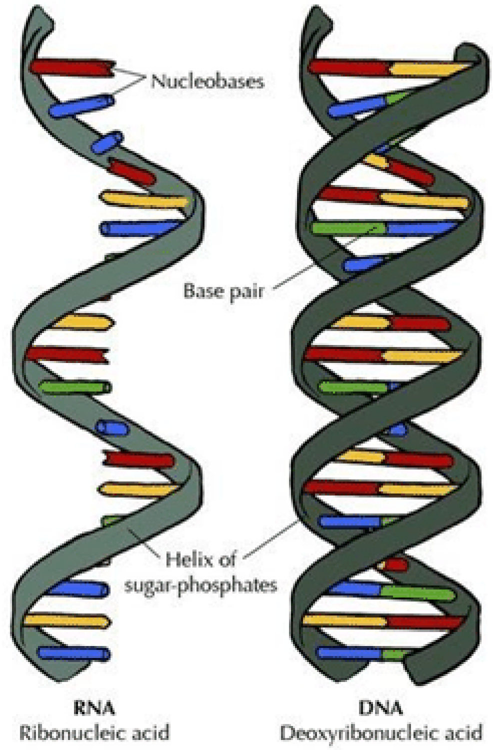
The Double Helix

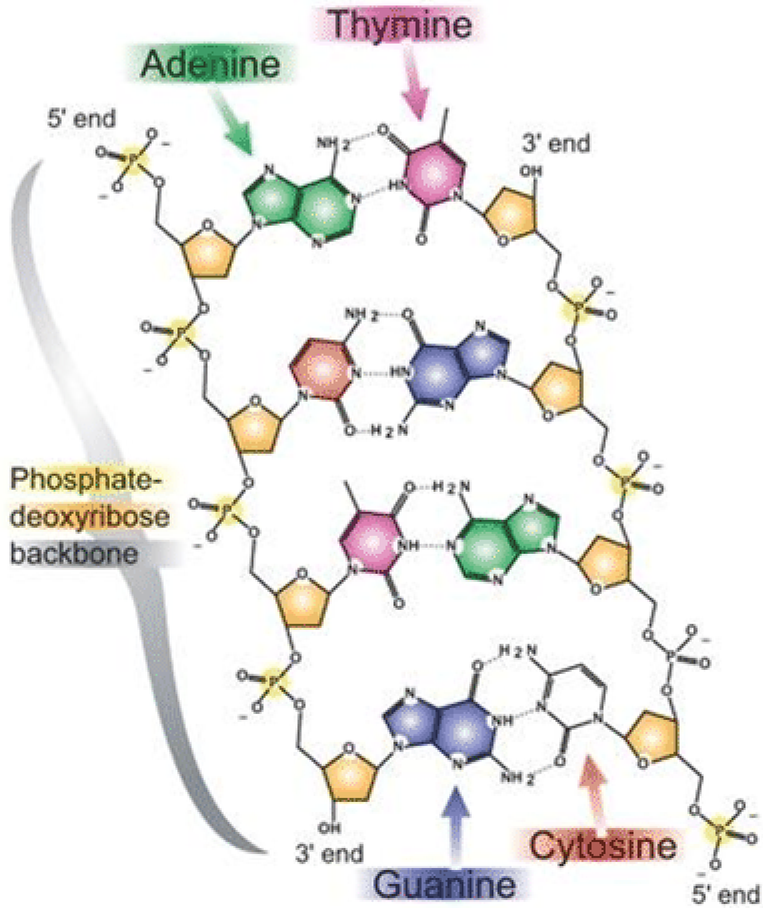
In the early 1950s, Rosalind Franklin started working on understanding the structure of DNA fibers. Franklin, together with Maurice Wilkins, used her expertise in x-ray diffraction photographic techniques to analyze the structure of DNA. In February 1953, Francis Crick and James D. Watson of the Cavendish Laboratory in Cambridge University had started to build a model of DNA. Watson and Crick indirectly obtained Franklin's DNA X-ray diffraction data demonstrating crucial information into the DNA structure. Francis Crick and James Watson then published their double helical model of DNA in Nature on April 25th, 1953.

Rosalind Franklin (left), James Watson (center) and Francis Crick (right).

DNA has the shape of a double helix, just like a spiral staircase. There are two sides, called the sugar-phosphate backbone, because they are made from alternating phosphate groups and deoxyribose sugars. The “steps” of the double helix are made from the base pairs formed between the nitrogenous bases. The DNA double helix is

held together by hydrogen bonds between the bases attached to the two strands.



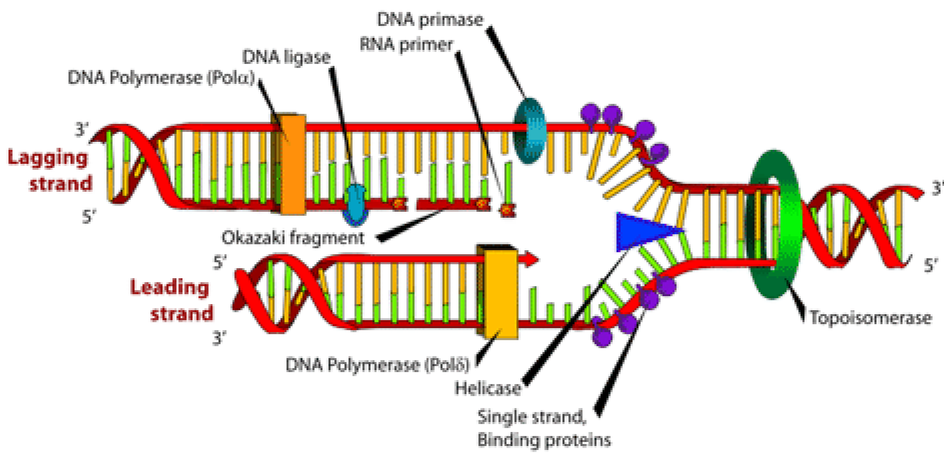


So it is this four letter code, made of just A, C, G, and T, that determines what the organism will become and what it will look like. How can these four bases carry so much information? This information results from the order of these four bases in the chromosomes. This sequence carries the unique genetic information for each species and each individual. For example, the DNA sequences between two species of reptiles will be more similar than between a reptile and an elm tree.

DNA sequences can be used for scientific, medical, and forensic purposes. DNA sequences can be used to establish evolutionary relationships between species, to determine a person's susceptibility to inherit or develop a certain disease, or to identify crime suspects or victims. Of course, DNA analysis can be used for other purposes as well. So why is DNA so useful for these purposes? It is useful because every cell in an organism has the same DNA sequence. For this to occur, each cell must have a mechanism to copy its entire DNA. How can so much information be exactly copied in such a small amount of time?

DNA replication is the process in which a cell's entire DNA is copied, or replicated. This process occurs during the Synthesis (S) phase of the eukaryotic cell cycle. As each DNA strand has the same genetic information, both strands of the double helix can

serve as templates for the reproduction of a new strand. The two resulting double helices are identical to the initial double helix.



DNA replication. The two DNA strands are opened by helicase. The strands are held open by a single strand of binding proteins, once DNA is relaxed it is copied and put back together.

RNA: How is it related to DNA?

DNA → RNA → Protein

“DNA makes RNA which makes protein.” So what exactly is RNA? Ribonucleic acid, or RNA, is the other important nucleic acid in the three player act. When we say that “DNA makes RNA which makes protein,” what do we mean? We mean that the information in DNA is somehow transferred into RNA, and that the information in RNA is then used to make the protein.

DNA has 4 bases often recognized by their first letter, A, T, C, G. The order they are put together determines which amino acids will be formed. The order that the amino acids are placed together determines what proteins are made. DNA making protein is similar to letters of the alphabet make sentences. Letters of the alphabet are placed in a certain order to form words and those words are placed in a certain order to form a sentence.

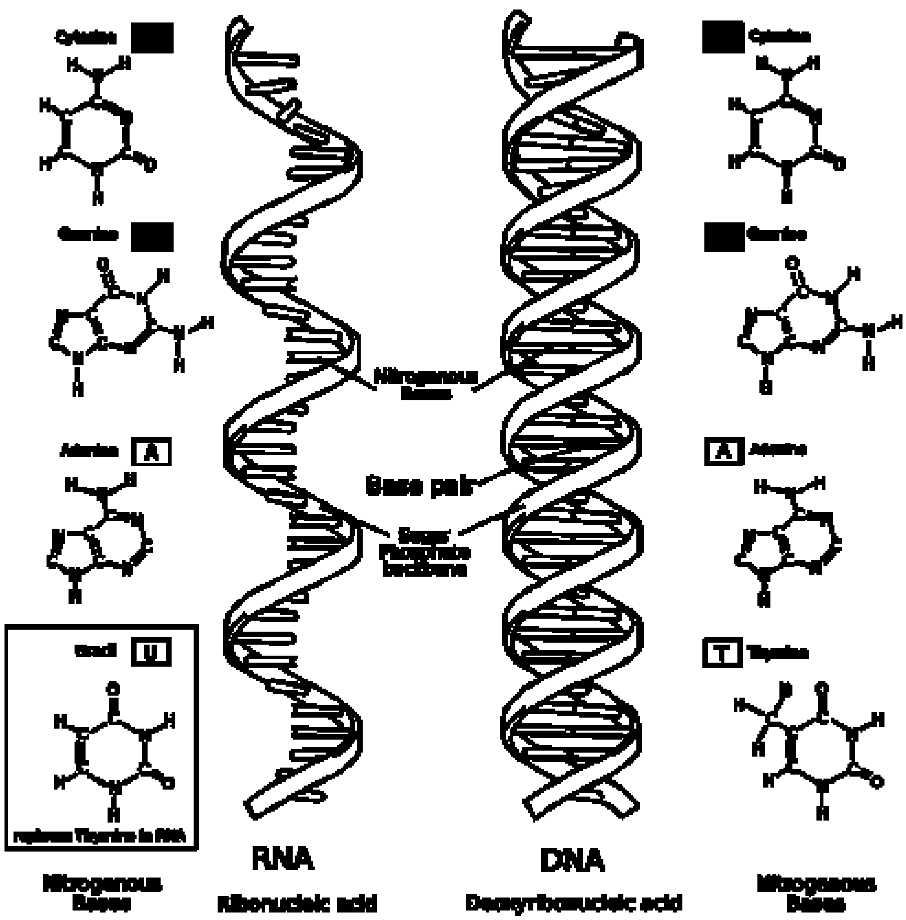
DNA	Alphabet
RNA	Sequence of letters
Amino Acid Sequence	Forms words
Makes proteins	Makes a sentence

To understand this, it helps to first understand RNA. A gene is a segment of DNA that contains the information necessary to encode an RNA molecule or a protein. Keep in mind that even though you have many thousands of genes, not all are used in every cell type. In fact, probably only a few thousand are used in a particular type of cell, with different cell types using different genes. However, while these genes are embedded in the large chromosomes that never leave the nucleus, the RNA is relatively small and is able to carry information out of the nucleus. The process of copying the information in DNA into information in RNA is called transcription.

RNA Structure

RNA structure differs from DNA in three specific ways. Both are nucleic acids and made out of nucleotides; however, RNA is single stranded while DNA is double stranded. RNA contains the 5-carbon sugar ribose, whereas in DNA, the sugar is deoxyribose. Though both RNA and DNA contain the nitrogenous bases adenine, guanine and cytosine, RNA contains the nitrogenous base uracil instead of thymine. Uracil pairs with adenine in RNA, just as thymine pairs with adenine in DNA. A comparison of RNA and DNA is shown in the Table below Comparison of RNA and DNA.

	RNA	DNA
	single stranded	double stranded
Specific Base	contains uracil	contains thymine
Sugar	Ribose	deoxyribose
Size	relatively small	big (chromosomes)
Location	moves to cytoplasm	stays in nucleus
Types	3 types: mRNA, tRNA, rRNA	generally 1 type



A comparison of RNA and DNA. RNA is single stranded and contains the base uracil, which replaces thymine.

Remember, proteins are made out of amino acids, so how does the information get converted from the language of nucleotides to the language of amino acids? The process is called translation.

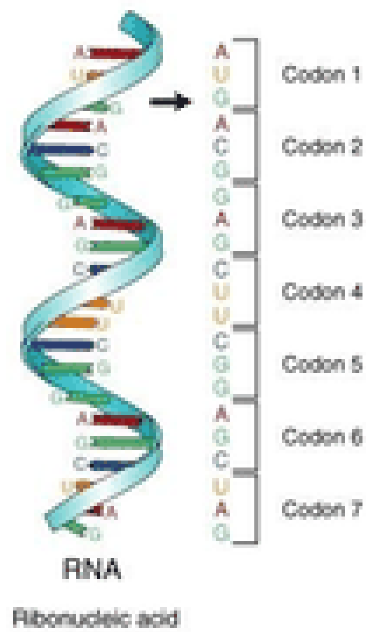
Translation

Translation is “RNA → protein”. In other words, translation is the transfer of the instructions in RNA to a protein made of amino acids. Translation takes place in the cytoplasm and interacts with a ribosome.

The Genetic Code

So how exactly is the language of nucleotides used to code for the language of amino acids? How can a code of only As, Cs, Gs, and Us carry information for 20 different amino acids? The genetic code is the code in which the language of nucleotides is used to create the language of amino acids.

Cracking the Code



A code of at least three letters has to be the answer. A one letter code would only be able to code for four amino acids. A two letter code could only code for 16 amino acids. With a three letter code, there are 64 possibilities. As there are 20 amino acids, the answer must be a code of at least three letters.

In 1961, Francis Crick and Sydney Brenner demonstrated the presence of codons, that is, three bases of RNA that code for one amino acid (See figure). Also in 1961, Marshall Nirenberg and Heinrich Matthaei at the National Institutes of Health (NIH) discovered the nucleotide makeup of 54 of the 64 codons. Others determined the remainder of the genetic code codons.

The mRNA is divided into three-base segments called codons. A codon is the segment of nucleotides that codes for an amino acid, or for a start or stop signal. There are 64 codons.

		2nd base			
		U	C	A	G
1st base	U	UUU (Phe/F) Phenylalanine	UCU (Ser/S) Serine	UAU (Tyr/Y) Tyrosine	UGU (Cys/C) Cysteine
		UUC (Phe/F) Phenylalanine	UCC (Ser/S) Serine	UAC (Tyr/Y) Tyrosine	UGC (Cys/C) Cysteine
		UUA (Leu/L) Leucine	UCA (Ser/S) Serine	UAA Ochre (*Stop*)	UGA Opal (*Stop*)
		UUG (Leu/L) Leucine	UCG (Ser/S) Serine	UAG Amber (*Stop*)	UGG (Trp/W) Tryptophan
	C	CUU (Leu/L) Leucine	CCU (Pro/P) Proline	CAU (His/H) Histidine	CGU (Arg/R) Arginine
		CUC (Leu/L) Leucine	CCC (Pro/P) Proline	CAC (His/H) Histidine	CGC (Arg/R) Arginine
		CUA (Leu/L) Leucine	CCA (Pro/P) Proline	CAA (Gln/Q) Glutamine	CGA (Arg/R) Arginine
		CUG (Leu/L) Leucine	CCG (Pro/P) Proline	CAG (Gln/Q) Glutamine	CGG (Arg/R) Arginine
	A	AUU (Ile/I) Isoleucine	ACU (Thr/T) Threonine	AAU (Asn/N) Asparagine	AGU (Ser/S) Serine
		AUC (Ile/I) Isoleucine	ACC (Thr/T) Threonine	AAC (Asn/N) Asparagine	AGC (Ser/S) Serine
		AUA (Ile/I) Isoleucine	ACA (Thr/T) Threonine	AAA (Lys/K) Lysine	AGA (Arg/R) Arginine
		AUG[A] (Met/M) Methionine	ACG (Thr/T) Threonine	AAG (Lys/K) Lysine	AGG (Arg/R) Arginine
	G	GUU (Val/V) Valine	GCU (Ala/A) Alanine	GAU (Asp/D) Aspartic acid	GGU (Gly/G) Glycine
		GUC (Val/V) Valine	GCC (Ala/A) Alanine	GAC (Asp/D) Aspartic acid	GGC (Gly/G) Glycine
		GUA (Val/V) Valine	GCA (Ala/A) Alanine	GAA (Glu/E) Glutamic acid	GGA (Gly/G) Glycine
		GUG (Val/V) Valine	GCG (Ala/A) Alanine	GAG (Glu/E) Glutamic acid	GGG (Gly/G) Glycine

nonpolar	polar	basic	acidic	(stop codon)

The Genetic Code.

The Genetic Code: Codons are in the mRNA sequence. The three letter and one letter code for the amino acids are shown. There are 64 codons that code for 20 amino acids and three stop codons, so an amino acid may have more than one corresponding codon.

Start and Stop Codons

The codon AUG codes for the amino acid methionine. This codon is also the start codon which begins every translation of every amino acid chain. There are three stop codons: UAG, UGA, UAA.

Mutations: Can my DNA change?

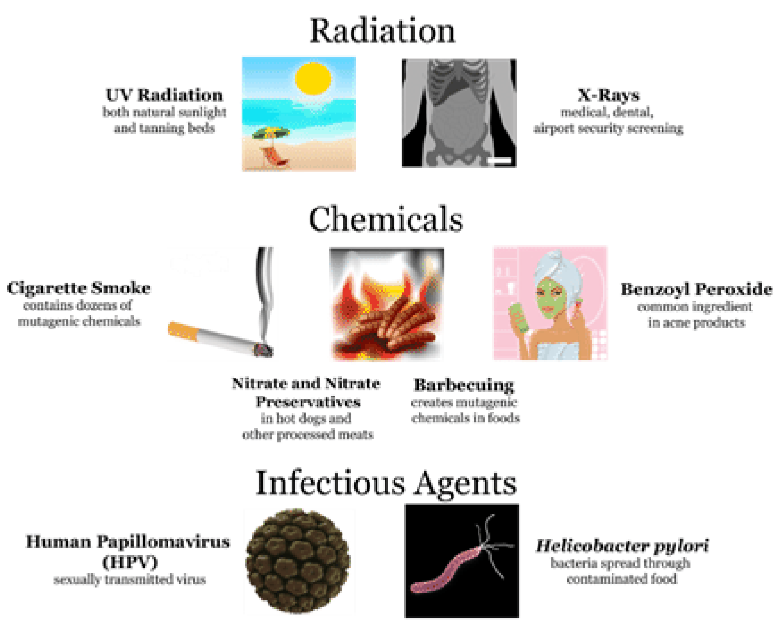
A mutation is a change in the DNA or RNA sequence, and many mutations result in new alleles. Some of these changes can be beneficial. In fact, evolution could not take place without the genetic variation that results from mutations. But some mutations are harmful. There are also chromosomal mutations, large changes with dramatic effects.

Causes of Mutation

Is it possible for mutations to occur spontaneously, or does there have to be a cause of the mutation? Well, the answer is that both are possible. A spontaneous mutation can just happen, possibly due to a mistake during DNA replication or transcription. Mutations may also occur during mitosis and meiosis. A mutation caused by an environmental factor, or mutagen, is known as an induced mutation. Typical mutagens include chemicals, like those inhaled while smoking, and radiation, such as X-rays, ultraviolet light, and nuclear radiation.

For a video about mutagens, go the link below.

- http://go.uen.org/b2e (0:36)



Examples of Mutagens. Types of mutagens include radiation, chemicals, and infectious agents. Do you know of other examples of each type of mutagen shown here?

Types of Mutations

Various types of mutations can all have severe effects on the individual. These include point mutations, frameshift mutations and chromosomal alterations.

Mutations that disrupt the reading frame by insertions or deletions of a non-multiple of 3 nucleotide bases are known as frameshift mutations. Take the example:

MR BLAKE IS A GOOD TEACHER

A deletion mutation that disrupts the reading frame, results in a message that does not make any sense or adds a different meaning. If an 'O' is deleted:

MR BLAKE IS A GOD TEACHER

Now Mr. Blake is a teacher of Gods. Who did teach Zeus? Was Mr. Blake Thor's tutor when he was a child?

An insertion mutation that disrupts the reading frame, results in a message that does not make any sense or adds a different meaning. If an 'S' is inserted:

MRS BLAKE IS A GOOD TEACHER

Now the gender of the teacher is changed which gives you a new picture of who your teacher is.

If the reading frame is disrupted, as in these frameshift mutations, the RNA may not be translated properly. These mutations may impair the function of the resulting protein, if the protein is even formed. Many frameshift mutations result in a premature stop codon, in other words, a stop codon that comes earlier than normal during translation. This would result in a smaller protein, most likely without normal function.

Point mutations are different because they do not change the three letter reading frame of the codon. Instead, a single letter base is replaced with a different letter. For example,

MR BLAKE IS A GOON TEACHER

This kind of point mutation will generally change only one amino acid in the protein, or might not change the amino acid sequence at all. Sometimes these mutations are not harmful, but sometimes they can be devastating. Tay-Sachs disease is an example of a fatal disease that occurs because of a single letter change in the DNA code.

Go to this link for a video about chromosomal alterations:

- http://go.uen.org/b2f

Most mutations have no benefit or harm to the organism. A cell that has a mutation may die off on its own before it can reproduce, or the mutation may not affect the function of the cell so the mutation is never noticed. Some mutations are beneficial while others are harmful.

Beneficial Mutations: What good can come of this?

Some mutations have a positive effect on the organism in which they occur. They are called beneficial mutations. They lead to new versions of proteins that help organisms

adapt to changes in their environment. Beneficial mutations are essential for evolution to occur. They increase an organism’s chances of surviving or reproducing, so they are likely to become more common over time. There are several well-known examples of beneficial mutations. Here are just three:

Mutations in many bacteria that allow them to survive in the presence of antibiotic drugs. The mutations lead to antibiotic-resistant strains of bacteria.

A unique mutation is found in people in a small town in Italy. The mutation protects them from developing atherosclerosis, which is the dangerous buildup of fatty materials in blood vessels. The individual in which the mutation first appeared has never been identified.

Harmful Mutations

Imagine making a random change in a complicated machine such as a car engine. The chance that the random change would improve the functioning of the car is very small. The change is far more likely to result in a car that does not run well or perhaps does not run at all. By the same token, any random change in a gene's DNA is likely to result in a protein that does not function normally or may not function at all. When a mutation alters a protein that plays a critical role in the cell, the tissue, organ, or organ system may not function properly, resulting in a medical condition. Such mutations are likely to be harmful. Harmful mutations may cause genetic disorders or cancer.

A genetic disorder is a disease caused by a mutation in one or a few genes. A human example is cystic fibrosis. A mutation in a single gene causes the body to produce thick, sticky mucus that clogs the lungs and blocks ducts in digestive organs.

You can watch a video about cystic fibrosis and other genetic disorders at this link:

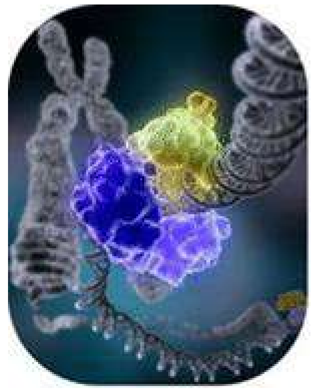
- http://go.uen.org/b2g (9:31)

Cancer is a disease in which cells grow out of control and form abnormal masses of cells. It is generally caused by mutations in genes that regulate the cell cycle. Because of the mutations, cells with damaged DNA are allowed to divide without limits. Cancer genes can be inherited.

You can learn more about hereditary cancer by watching the video at the following link:

- http://go.uen.org/b2h (4:29)

Often, these mutations are repaired by the DNA repair system of the cell. Each cell has a number of pathways through which enzymes recognize and repair mistakes in DNA (See next figure). Because DNA can be damaged or mutated in many ways, the process of DNA repair is an important way in which the cell protects itself to maintain proper function.



DNA repair. Shown is a model of DNA ligase repairing chromosomal damage.

Mutations and Cancer

Cancer is unregulated cell division. That is, cancer is a disease characterized by a population of cells that grow and divide despite the mutations they have. Malignant cancerous cells invade and destroy adjacent tissues, and they may spread throughout the body. A benign tumor is one that has not spread to any other tissues.

Nearly all cancers are caused by mutations in the DNA of the abnormal cells. These mutations may be due to the effects of carcinogens, cancer causing agents such as tobacco smoke, radiation, chemicals, or infectious agents. These carcinogens may act as an environmental “trigger”, stimulating the onset of cancer in certain individuals and not others. Do all people who smoke get cancer? No. Complex interactions between carcinogens and an individual’s genome may explain why only some people develop cancer after exposure to an environmental trigger and others do not. Do all cancers need an environmental trigger to develop? No. Cancer causing mutations may also result from errors incorporated into the DNA during replication, or they may be inherited. Inherited mutations are present in all cells of the organism.

Summary

- Watson and Crick demonstrated the double helix model of DNA based on Franklin's work with photographs of x-ray diffraction.
- The base pairing rules discovered by Chargaff state that A always pairs with T and G always pairs with C.
- DNA replication is the process by which a cell’s entire DNA is copied, or replicated.
- RNA is a single-stranded nucleic acid, which contains the nitrogenous base uracil.
- Mutations may be due to environmental factors (mutagens) or may occur spontaneously.
- Typical mutagens include chemicals, such as those inhaled by smoking, and radiation, like X-rays, ultraviolet light, and nuclear radiation.
- A deletion or insertion in the DNA can alter the reading frame.

- Beneficial mutations may accumulate in a population, resulting, over time, in evolution.
- Harmful mutations can result in errors in protein sequence, creating partially or completely non-functional proteins.

Online Interactives/Simulations

Transcription Animation.

- http://go.uen.org/b2i

Genetic Science Learning Center

- http://go.uen.org/b2j

Biology Web Labs Dragon Genetics & Mendel's Peas.

- http://go.uen.org/b2k

Think like a Geneticist

1. Discuss how DNA was identified as the genetic material.

2. What are the base pairing rules?

3. What are the parts of Watson and Crick's double helix model of DNA?

4. What is the importance of DNA replication in cell reproduction?

5. How does DNA make proteins?

6. How is RNA different from DNA?

7. What is meant by "DNA → RNA → Amino acids → Protein"?

8. What is a codon?

9. What is a Mutation?

10. What is a mutagen and what are some examples?

11. What is an example of a beneficial mutation?

12. What is an example of a harmful mutation?

13. “DNA → RNA” Can you think of a method in which the information in DNA is transferred to an RNA molecule?

CHAPTER 5

Standard V: Evolution

Chapter Outline

Standard 5: Students will understand that biological diversity is a result of evolutionary processes.

Objective 1: Relate principles of evolution to biological diversity.

a. Describe the effects of environmental factors on natural selection.

b. Relate genetic variability to a species' potential for adaptation to a changing environment.

c. Relate reproductive isolation to speciation.

d. Compare selective breeding to natural selection and relate the differences to agricultural practices.

Objective 2: Cite evidence for changes in populations over time and use concepts of evolution to explain these changes.

a. Cite evidence that supports biological evolution over time (e.g., geologic and fossil records, chemical mechanisms, DNA structural similarities, homologous and vestigial structures).

b. Identify the role of mutation and recombination in evolution.

c. Relate the nature of science to the historical development of the theory of evolution.

d. Distinguish between observations and inferences in making interpretations related to evolution (e.g., observed similarities and differences in the beaks of Galapagos finches leads to the inference that they evolved from a common ancestor; observed similarities and differences in the structures of birds and reptiles leads to the inference that birds evolved from reptiles).

e. Review a scientific article and identify the research methods used to gather evidence that documents the evolution of a species.

Objective 3: Classify organisms into a hierarchy of groups based on similarities that reflect their evolutionary relationships.

a. Classify organisms using a classification tool such as a key or field guide.

b. Generalize criteria used for classification of organisms (e.g., dichotomy, structure, broad to specific).

c. Explain how evolutionary relationships are related to classification systems.

d. Justify the ongoing changes to classification schemes used in biology.

Unit Key Vocabulary

- Evolution
- Fossil Record
- Geological Record
- Molecular
- Homologous
- Vestigial Structures
- Mutation
- Recombination
- Hierarchy
- Classification Scheme
- Theory
- Natural Selection
- Adaption
- Evidence
- Inference
- Speciation
- Biodiversity
- Taxonomy
- Kingdom
- Virus
- Protist
- Fungi
- Plant
- Animal
- Dichotomy

5.1 Evidence of Evolution

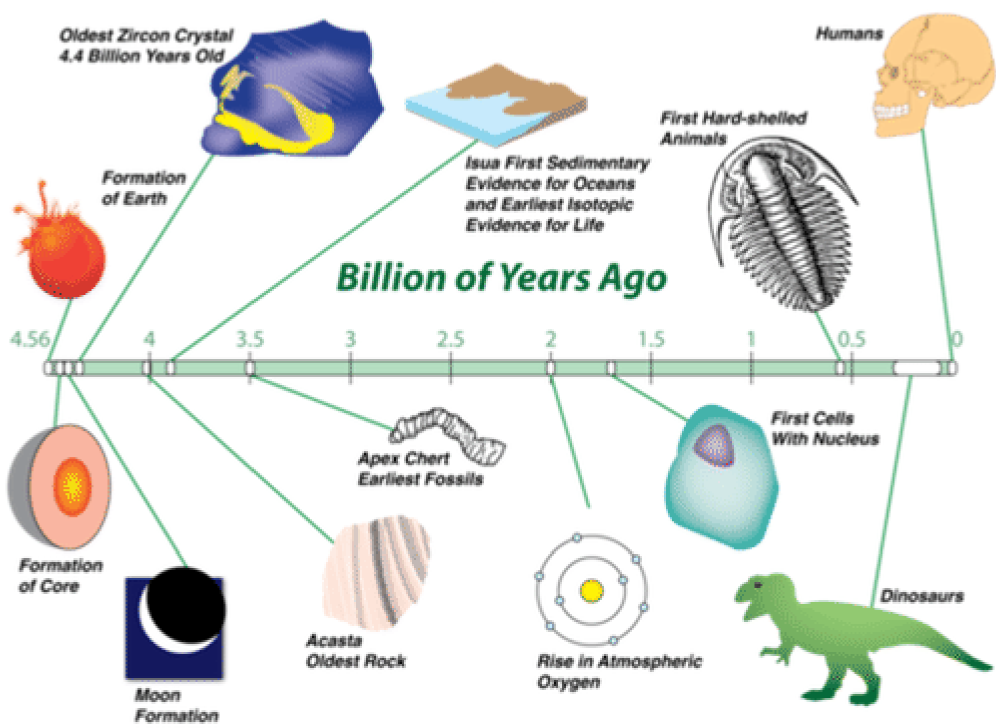
When did life on Earth appear?

Objectives

- Cite evidence that supports biological evolution over time.
- Relate the nature of science to the historical development of the theory of evolution.

Introduction

Earth formed 4.6 billion years ago, and life first appeared about 4 billion years ago. The first life forms were microscopic, single-celled organisms. From these simple beginnings, evolution (change over time) gradually produced the vast complexity and diversity of life today. The evolution of life on Earth wasn't always smooth and steady—far from it. Living things had to cope with some astounding changes. Giant meteorites struck Earth's surface. Continents drifted and shifted. Ice ages buried the planet in snow and ice for millions of years at a time. At least five times, many, if not most, of Earth's living things went extinct. Extinction occurs when a species completely dies out and no members of the species remain. But life on Earth was persistent. Each time, it came back more numerous and diverse than before.



This timeline shows the history of life on Earth. In the entire span of the time, humans are a relatively new addition.

Earth in a Day

It's hard to grasp the vast amounts of time since Earth formed and life first appeared on its surface. It may help to think of Earth's history as a 24-hour day (See figure). Humans would have appeared only during the last minute of that day. If we are such newcomers on planet Earth, how do we know about the vast period of time that went before us? How have we learned about the distant past?

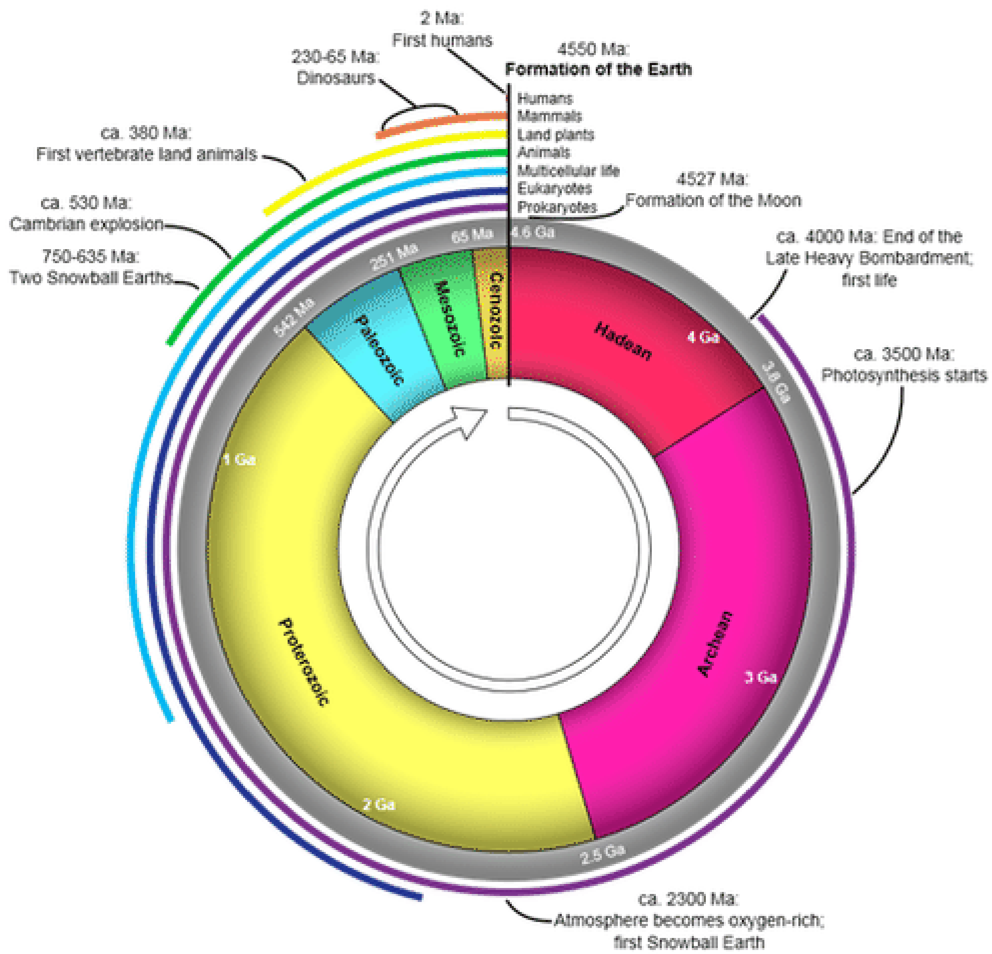


Diagram of the 24 hour clock model of Earth's History.

Fossils: What can fossils tell us about the past

Objectives

- Cite evidence that supports biological evolution over time.
- Relate the nature of science to the historical development of the theory of evolution.

Learning about the Past

In his book *On the Origin of Species*, Charles Darwin included evidence to show that evolution had taken place. He also made logical arguments to support his theory that evolution occurs by natural selection. Since Darwin's time a great deal more evidence has been gathered. The evidence includes a huge number of fossils. In fact, much of what we know today about the history of life on Earth is based on the fossil record. Detailed knowledge of modern organisms also helps us understand how life evolved.

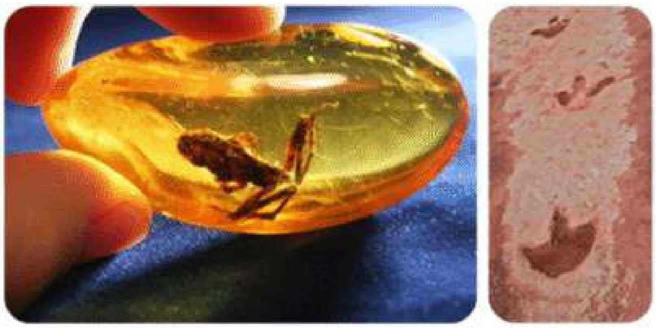
The Fossil Record

Fossils are the preserved remains or traces of organisms that lived long ago which provide clear evidence that evolution has occurred. Scientists who find and study fossils are called paleontologists.

The soft parts of organisms almost always decompose quickly after death. On occasion, the hard parts — mainly bones, teeth, or shells — remain long enough to mineralize and form fossils. An example of a complete fossil skeleton is shown in the Figure below. The fossil record (the record of life that unfolded over four billion years) has been pieced back together through the analysis of fossils.

Extinct Lion Fossil. This fossilized skeleton represents an extinct lion species. It is rare for fossils to be so complete and well preserved as this one.

To be preserved as fossils, remains must be covered quickly by sediments or preserved in some other way. For example, they may be frozen in glaciers or trapped in tree resin, like the frog in the figure below. Sometimes traces of organisms — such as footprints or burrows — are preserved (See next figure). The conditions required for fossils to form rarely occur. Therefore, the chance of an organism being preserved as a fossil is very low.



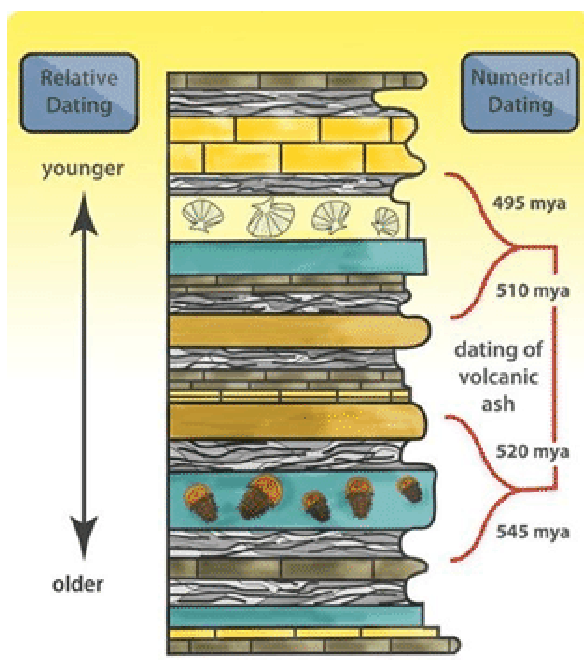
The photo on the left shows an ancient frog trapped in hardened tree resin, or amber. The photo on the right shows the fossil footprints of a dinosaur.

You can watch a video at the following link to see in more detail how fossils form:

- http://go.uen.org/b2l

In order for fossils to "tell" us the story of life, they must be dated. Then they can help scientists reconstruct how life changed over time. Fossils can be dated in two different ways: relative dating and absolute dating. Both are described below.

Relative dating determines which of two fossils is older or younger than the other, but not their age in years. Relative dating is based on the positions of fossils in rock layers. Lower layers were laid down earlier, so they are assumed to contain older fossils. (See figure).

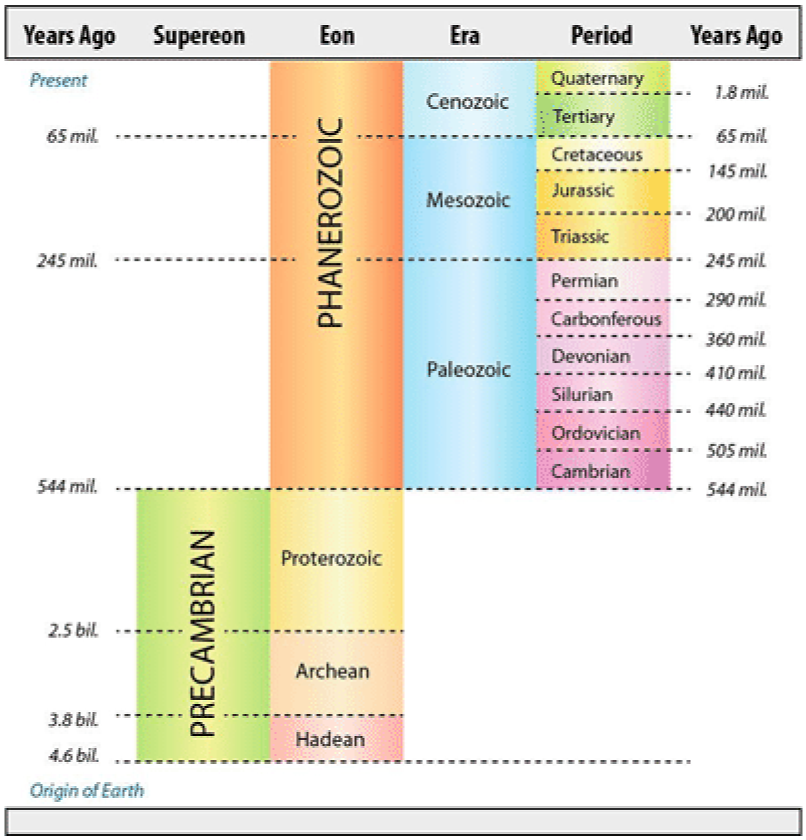


Relative Dating Using Rock Layers. Relative dating establishes which of two fossils is older than the other. It is based on the rock layers in which the fossils formed.

Absolute dating uses the molecular (combination of two or more atoms) –amount of carbon-14 or other radioactive element that remains in a fossil to determine about how long ago a fossilized organism lived. This gives the fossil an approximate age in years.

Geologic Time Scale

Another tool for understanding the history of Earth and its life is the geologic time scale (See figure). The geologic time scale divides Earth's history into divisions such as eons, eras, and periods that are based on major changes in geology, climate, and the evolution of life. It organizes Earth's history and the evolution of life on the basis of important events instead of time alone. It also allows more focus to be placed on recent events, about which we know the most.



Geologic Time Scale. The geologic time scale divides Earth's history into units that reflect major changes in Earth and its life forms. During which eon did Earth form? What is the present era?

Think like a Paleontologist

1. How old is the Earth? How long has there been life on Earth?
2. How do scientists measure the relative age of fossils? How do they measure the exact age of a fossil?
3. How do paleontologists contribute evidence to the theory of evolution?

Natural Selection: How Did Darwin Discover Natural Selection?

Objectives

- Describe the effects of environmental factors on natural selection.
- Cite evidence that supports biological evolution over time.
- Compare selective breeding to natural selection and relate the differences to agricultural practices.
- Relate the nature of science to the historical development of the theory of evolution.
- Distinguish between observations and inferences in making interpretations related to evolution.

Introduction

The Englishman Charles Darwin is one of the most influential scientists in the history of the biological sciences. His place in the history of science is well deserved as Darwin's theory – (an explanation supported by abundant evidence or data) - of evolution represents a giant leap in human understanding. Darwin's theories help to explain and unify all of biology.

Darwin's Theory at a Glance

Darwin's theory of evolution actually contains two major ideas:

- Evolution occurs. In other words, organisms change over time. Life on Earth has changed as descendants diverged from common ancestors in the past.
- Evolution occurs by natural selection which is the process in which living things with beneficial traits produce more offspring than those with less beneficial traits. This results in changes in the traits of living things over time.

In Darwin's day, most people believed that all species were created at the same time and remained unchanged thereafter. They also believed that Earth was only 6,000 years old. Therefore, Darwin's ideas revolutionized biology. How did Darwin come up with these important ideas? It all started when he went on a voyage.

The Voyage of the Beagle

In 1831, when Darwin was just 22 years old, he set sail as part of a scientific expedition on the ship called HMS Beagle. He was the naturalist on the voyage. As a naturalist, it was his job to observe and collect specimens of plants, animals, rocks, and fossils wherever the expedition went ashore.

Voyage of the Beagle. This map shows the route of Darwin's 5-year voyage on the HMS Beagle. Each stop along the way is labeled.

You can learn more about Darwin's voyage at this link:

- http://go.uen.org/b2m

Darwin's Observations

During the long voyage, Darwin made many observations that helped him form his theory of evolution.

For example:

- He visited tropical rainforests and other new habitats where he saw many plants and animals he had never seen before (See figure). The great diversity of life made a significant impression on Darwin.
- He experienced an earthquake that lifted the ocean floor 2.7 meters (9 feet) above sea level. He also found rocks containing fossil sea shells in mountains high above sea level. These observations suggested that continents and oceans had changed dramatically over time and continue to change in dramatic ways.
- Darwin visited rock ledges which had clearly once been beaches that gradually built up over time. This suggested that slow, steady processes also change Earth's surface.
- He dug up fossils of gigantic extinct mammals, such as the ground sloth (See figure). This was hard evidence that organisms looked very different in the past. Similar to the way Earth's surface changes, Darwin decided living things must change over time too.

On his voyage, Darwin saw (from left to right) giant marine iguanas, blue-footed boobies and he also dug up the fossil skeleton of a giant ground sloth like the one shown here.

The Galápagos Islands

Darwin's most important observations were made on the Galápagos Islands. This is a group of 16 small volcanic islands 966 kilometers (600 miles) off the west coast of South America.

Individual Galápagos Islands differ from one another in important ways. Some are rocky and dry. Others have better soil and more rainfall. Darwin noticed that the plants and animals on the different islands also differed. For example, the giant tortoises on one island had saddle-shaped shells, while those on another island had dome-shaped shells (See next figure). People who lived on the islands could even tell the island a turtle came from by the shape of its shell. This started Darwin thinking about the origin of species. He wondered how each island came to have its own type of tortoise.

Tortoise with saddle-shaped shell　　Tortoise with dome-shaped shell

Galápagos Tortoises. Galápagos tortoises have differently shaped shells depending on which island they inhabit. Tortoises with saddle-shaped shells can reach up to eat plant leaves above their head. Tortoises with dome-shaped shells cannot reach up in this way. These two types of tortoises live on islands with different environments and food sources.

Influences on Darwin

Science, like evolution, always builds on the past. Darwin didn't develop his theory completely on his own. He was influenced by the ideas of earlier thinkers.

Scientists Who Influenced Darwin

- Jean Baptiste Lamarck (1744–1829) was an important French naturalist. He was one of the first scientists to propose that species change over time. However, Lamarck was wrong about how species change. His idea of inheritance of acquired characteristics is incorrect. Traits an organism develops during its own lifetime cannot be passed on to offspring, as Lamarck believed.
- Charles Lyell (1797–1875) was a well-known English geologist. Darwin took his book, Principles of Geology, with him on the Beagle. In the book, Lyell argued that gradual geological processes have gradually shaped Earth's surface. From this, Lyell inferred that Earth must be far older than most people believed.
- Thomas Malthus (1766–1834) was an English economist. He wrote an essay titled On Population. In the essay, Malthus argued that human populations grow faster than the resources they depend on. When populations become too large, famine and disease break out. In the end, this keeps populations in check by killing off the weakest members.

Selective Breeding

These weren't the only influences on Darwin. He was also aware that humans could breed plants and animals to have useful traits. By selecting which animals were allowed to reproduce, they could change an organism's traits. Darwin called this type of change in organisms artificial selection. He used the word artificial to distinguish it from natural selection. Today we use the words 'Selective Breeding' to refer to the process humans use to "select" for certain desirable traits in agricultural processes and animal husbandry.

Selective Breeding in Pigeons. Pigeon hobbyists breed pigeons to have certain characteristics. Both of the pigeons in the bottom row were bred from the common rock pigeon.

Darwin’s Theory of Evolution by Natural Selection

Darwin spent many years thinking about the work of Lamarck, Lyell, and Malthus, what he had seen on his voyage, and artificial selection. He wondered what it all meant and how it all fit together. It’s easy to see how all of these influences helped shape Darwin’s theory of evolution by natural selection.

Progression of Darwin’s Theory

It took Darwin years to completely form his theory of evolution by natural selection. His reasoning went like this:

- Like Lamarck, Darwin assumed that species can change over time. The fossils he found helped convince him of that.
- From Lyell, Darwin saw that Earth and its life were very old. Thus, there had been enough time for evolution to produce the great diversity of life Darwin had observed.
- From Malthus, Darwin knew that populations could grow faster than their resources. This “overproduction of offspring” led to a “struggle for existence”, in Darwin’s words.
- From artificial selection, Darwin knew that some offspring have chance variations that can be inherited. In nature, offspring with certain variations might be more likely to survive the “struggle for existence” and reproduce. If so, they would pass their favorable variations to their offspring.

- Darwin coined the term fitness to refer to an organism's relative ability to survive and produce fertile offspring. Nature selects the variations that are most useful. Therefore, he called this type of selection natural selection.
- Darwin knew artificial selection could change domestic species over time. He inferred that natural selection could also change species over time. In fact, he thought that if a species changed enough, it might evolve into a new species.

Wallace's Theory

Did you ever hear the saying that "great minds think alike"? It certainly applies to Charles Darwin and his peer, English naturalist Alfred Russel Wallace. Wallace also traveled to distant places to study nature. He wasn't as famous as Darwin. However, he developed basically the same theory of evolution. While working in distant lands, Wallace sent Darwin a paper he had written. In the paper, Wallace explained his evolutionary theory. This served to confirm what Darwin already thought.

Wallace's paper not only confirmed Darwin's ideas. They pushed him to finish his book, *On the Origin of Species.* Published in 1859, this book changed our understanding of biological science forever. It clearly spelled out Darwin's theory of evolution by natural selection and provided convincing arguments and evidence to support it.

Applying Darwin's Theory

The following example applies Darwin's theory. It explains how giraffes came to have such long necks (See next figure).

- In the past, giraffes had short necks. But there was chance variation in neck length. Some giraffes had necks a little longer than the average.
- Then, as now, giraffes fed on tree leaves. Perhaps the environment changed, and leaves became scarcer. There would be more giraffes than the trees could support. Thus, there would be a "struggle for existence".
- Giraffes with longer necks had an advantage. They could reach leaves other giraffes could not. Therefore, the long-necked giraffes were more likely to survive and reproduce. They had greater fitness.
- These giraffes passed the long-neck trait to their offspring. Each generation, the population contained more long-necked giraffes. Eventually, all giraffes had long necks.

African Giraffes. Giraffes feed on leaves high in trees. Their long necks allow them to reach leaves that other ground animals cannot.

As this example shows, chance variations may help a species survive if the environment changes. Variation among species helps ensure that at least some will be able to survive environmental change.

It's been over 150 years since Charles Darwin published *On the Origin of Species.* Yet his ideas remain as central to biological scientific exploration as ever, and has been called the unifying concept of all biology.

Even today, it's rare for a biologist to predict the discovery of a new species. However, when Darwin observed an orchid from Madagascar with a foot-long nectary, he predicted that a pollinator would be found with a tongue long enough to reach the nectar inside the orchid's very thin, elongated nectar “pouch”, though he had never seen such a bird or insect. Darwin's prediction was based on his finding that all species are related to each other and that some of them evolve together, developing similar adaptations. His prediction came true in 1903, when a moth was discovered in Madagascar with a long, thin proboscis, which it uncurls to reach the nectar in the orchid's nectary. In the process of feeding from the orchid, the moth serves as its pollinator. The moth was given the scientific name Xanthopan morganii praedicta, in honor of Darwin’s prediction.

Summary

- Darwin's theory of evolution by natural selection states that living things with beneficial traits produce more offspring than others do. This produces changes in the traits of living things over time.
- During his voyage on the Beagle, Darwin made many observations that helped him develop his theory of evolution. His most important observations were made on the Galápagos Islands.
- Darwin was influenced by other early thinkers, including Lamarck, Lyell, and Malthus. He was also influenced by his knowledge of artificial selection.
- Wallace's paper on evolution confirmed Darwin's ideas. It also pushed him to publish his book, On the Origin of Species. The book clearly spells out his theory. It also provides evidence and logic to support it.

Think like a Naturalist

1. State Darwin's theory of evolution by natural selection.

2. What is the inheritance of acquired characteristics? What scientist developed this mistaken idea?

3. Apply Darwin's theory of evolution by natural selection to a specific case. For example, explain how Galápagos tortoises could have evolved saddle-shaped shells.

4. Why did Darwin's observations of Galápagos tortoises' shells cause him to wonder how species originate?

5. Explain how the writings of Charles Lyell and Thomas Malthus helped Darwin develop his theory of evolution by natural selection.

Points to Consider

Darwin's book *On the Origin of Species* is a major milestone in biology and other scientific fields. It introduced biology's most important theory. It also provided an excellent example of how to think like a scientist. A scientist uses evidence and logic to understand the natural world. In this lesson, you read about some of the evidence Darwin used. This evidence included fossils and artificial selection.

- What other evidence might be used to show that evolution occurs? What about evidence based on molecules?

Evidence: How is Evolution Supported by Evidence?

Objectives

- Cite evidence that supports biological evolution over time.
- Distinguish between observations and inferences in making interpretations related to evolution.

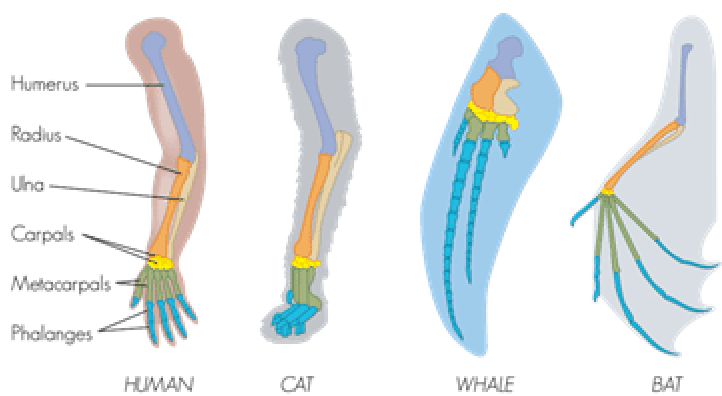
Evidence from Living Species

Just as Darwin did, today's scientists study living species to learn about evolution. They compare the anatomy, embryos, and DNA of modern organisms to understand how they evolved.

Comparative Anatomy

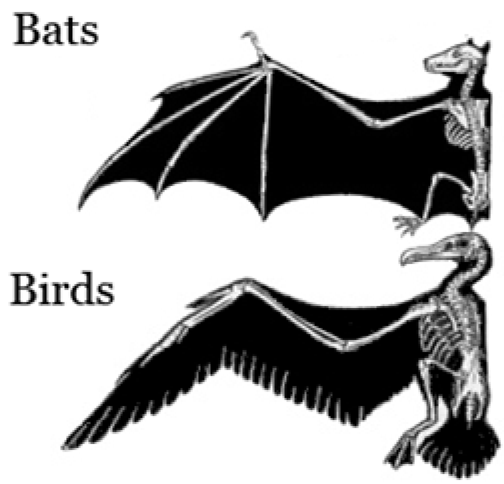
Comparative anatomy is the study of the similarities and differences in the structures of different species. Similar body parts may be homologies or analogies. Both provide evidence for evolution.

Homologous – (structures that are similar in related organisms because they were inherited from a common ancestor). These structures may or may not have the same function in the descendants. The figure below shows the hands of several different mammals. They all have the same basic pattern of bones. They inherited this pattern from a common ancestor. However, their forelimbs now have different functions.



Hands of Different Mammals. The forelimbs of all mammals have the same basic bone structure.

Analogous – (structures that are similar in unrelated organisms). The structures are similar because they evolved to do the same job, not because they were inherited from a common ancestor. For example, the wings of bats and birds, shown in the figure look similar on the outside. They also have the same function. However, wings evolved independently in the two groups of animals. This is apparent when you compare the pattern of bones inside the wings.



Wings of Bats and Birds. Wings of bats and birds serve the same function. Look closely at the bones inside the wings. The differences show they developed from different ancestors.

Comparative Embryology

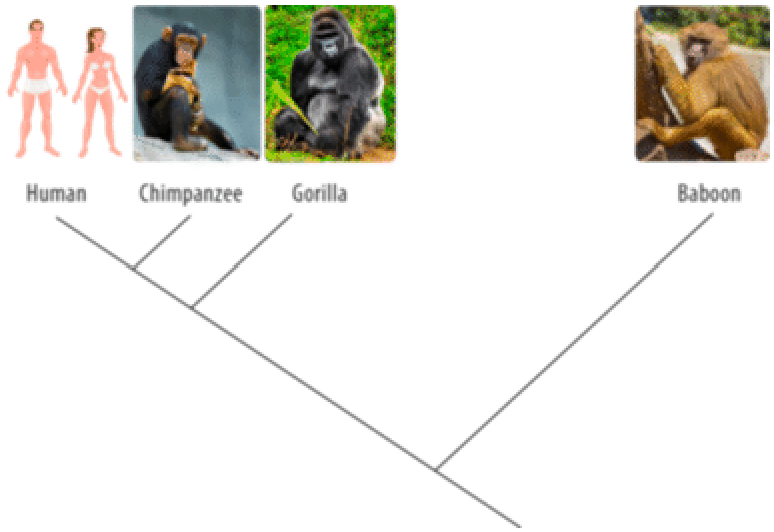
Comparative embryology is the study of the similarities and differences in the embryos of different species. Similarities in embryos are evidence of common ancestry. All vertebrate embryos, for example, have gill slits and tails. All of the animals in the figure, except for fish, lose their gill slits by adulthood. Some of them also lose their tail. In humans, the tail is reduced to the tail bone. Thus, similarities organisms share as embryos may be gone by adulthood. This is why it is valuable to compare organisms in the embryonic stage.
See: http://go.uen.org/b2n

Vestigial Structures

Structures like the human tail bone are called vestigial (structures that no longer serve a purpose to the organism) structures. Evolution has reduced their size because the structures are no longer used. The human appendix is another example of a vestigial structure. It is a tiny remnant of a once-larger organ. In a distant ancestor, it was needed to digest food. It serves no purpose in humans today. Why do you think structures that are no longer used shrink in size? Why might a full-sized, unused structure reduce an organism's fitness?

Comparing DNA

Darwin could compare only the anatomy and embryos of living things. Today, scientists can compare their DNA. Similar DNA sequences are the strongest evidence for evolution from a common ancestor. Look at the cladogram in the figure. It shows how humans and apes are related based on their DNA sequences.



Cladogram of Humans and Apes. This cladogram is based on DNA comparisons. It shows how humans are related to apes by descent from common ancestors.

Evolution and molecules are discussed at:

- http://go.uen.org/b2o
- http://go.uen.org/b2p

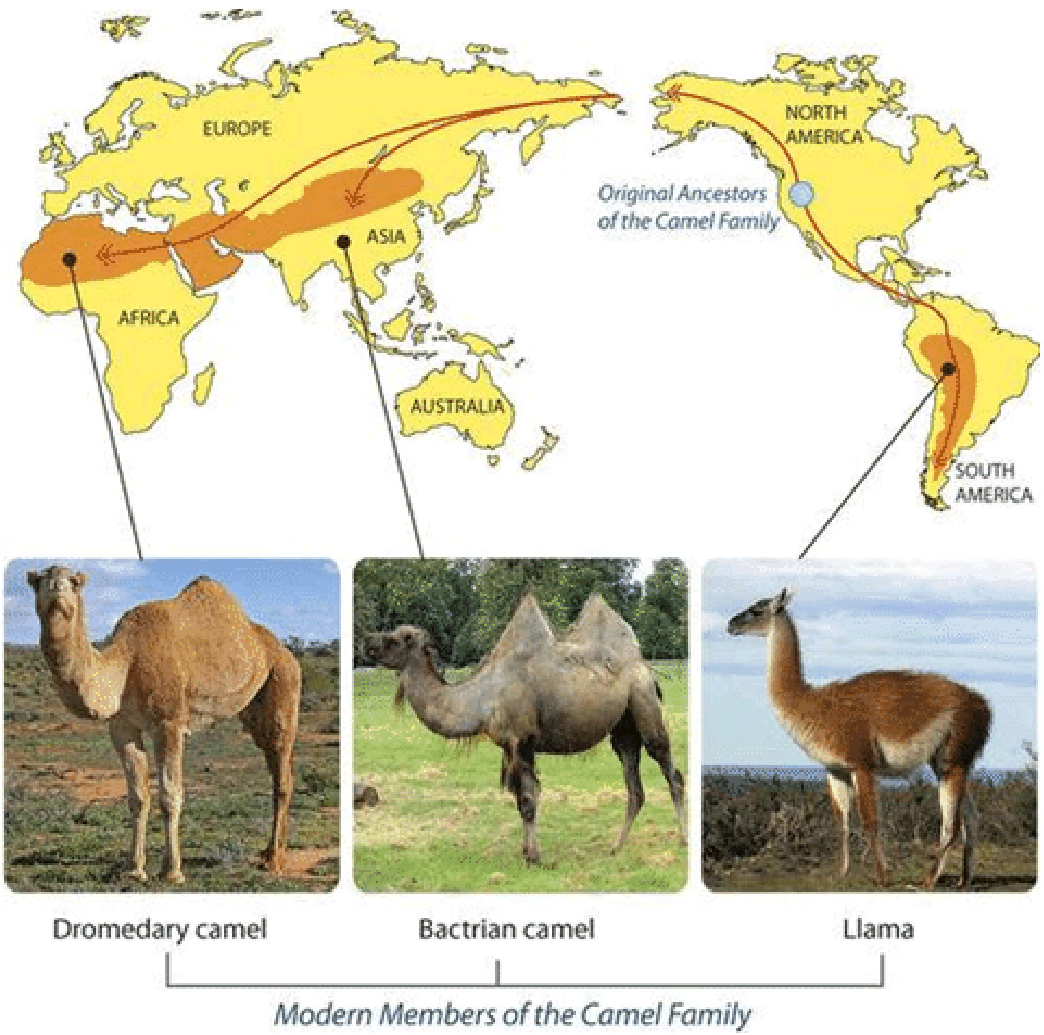
Evidence from Biogeography

Biogeography is the study of how and why plants and animals live where they do. It provides more evidence for evolution. Let's consider the camel family as an example.

Biogeography of Camels: An Example

Today, the camel family includes different types of camels. All of today's camels are descended from the same camel ancestors. These ancestors lived in North America about a million years ago.

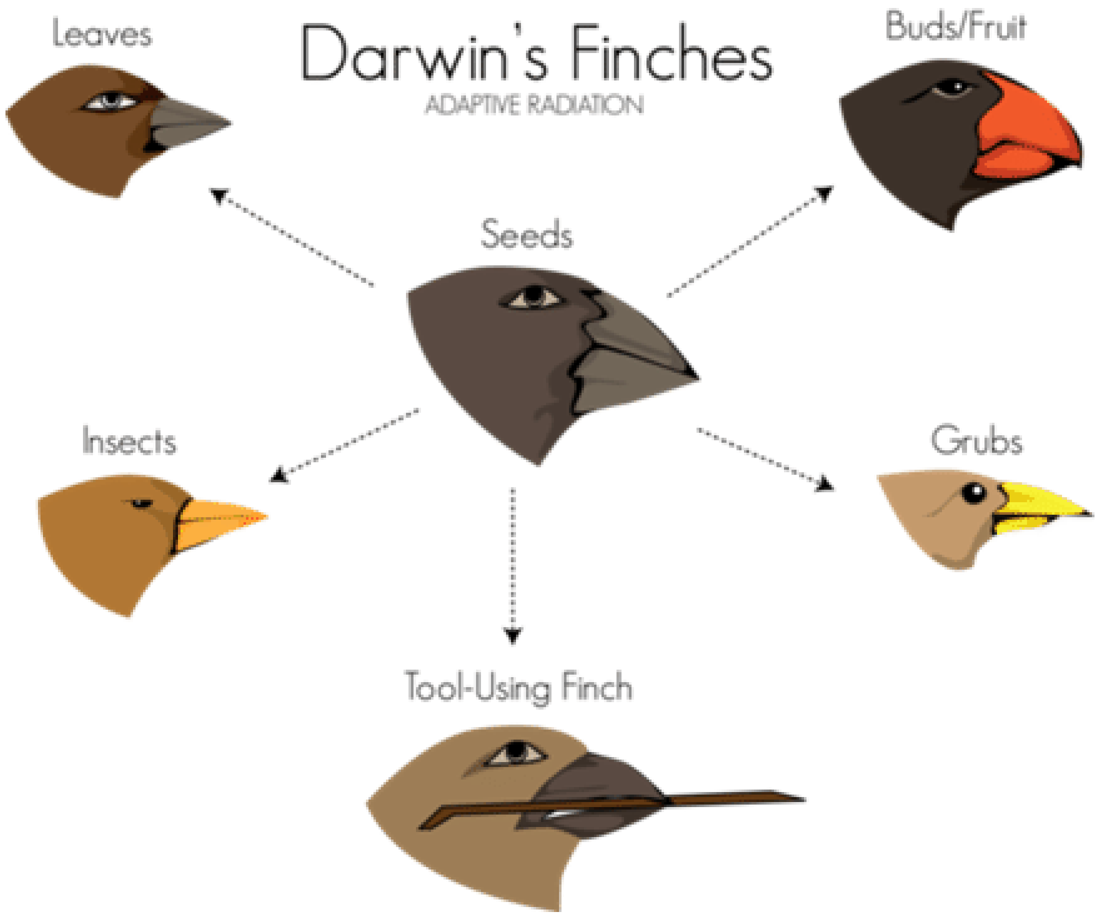
Early North American camels migrated to other places. Some went to East Asia. They crossed a land bridge during the last ice age. A few of them made it all the way to Africa. Others went to South America. They crossed the Isthmus of Panama. Once camels reached these different places, they evolved independently. They evolved adaptations that suited them for the particular environment where they lived. Through natural selection, descendants of the original camel ancestors evolved the diversity they have today.



Camel Migrations and Present-Day Variation. Members of the camel family now live in different parts of the world. They differ from one another in a number of traits and share similarities.

Island Biogeography

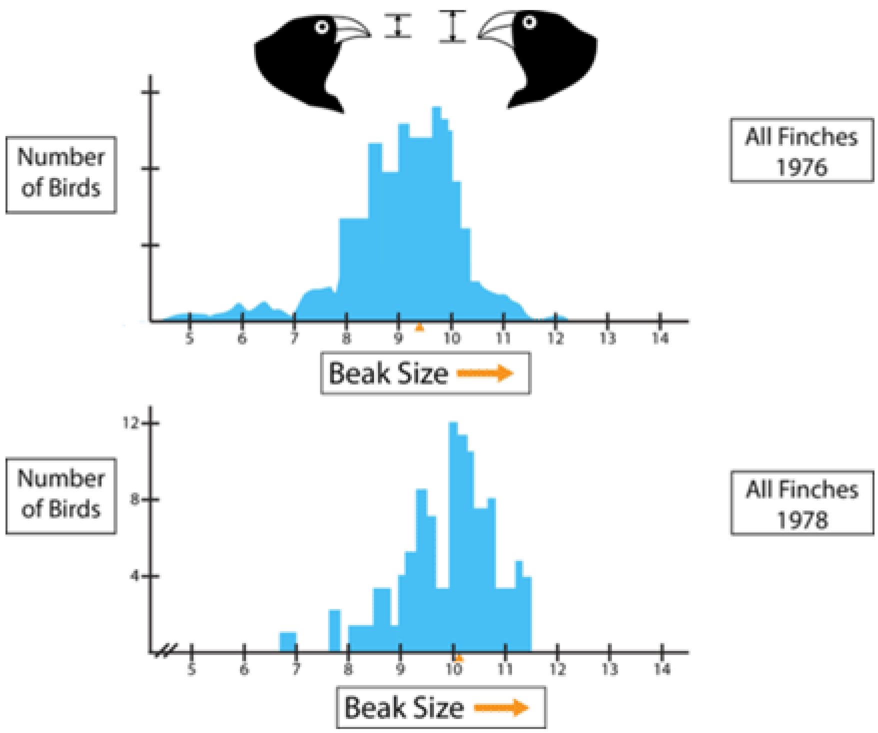
The biogeography of islands yields some of the best evidence for evolution. Consider the birds called finches that Darwin studied on the Galápagos Islands (See figure). All of the finches probably descended from one bird that arrived on the islands from South America. Until the first bird arrived, there had never been birds on the islands. The first bird was a seed eater. It evolved into many finch species. Each species was adapted for a different type of food. This is an example of adaptive radiation. This is the process by which a single species evolves into many new species to fill available niches.



Galápagos finches differ in beak size and shape, depending on the type of food they eat.

Eyewitness to Evolution

In the 1970s, biologists Peter and Rosemary Grant went to the Galápagos Islands. They wanted to re-study Darwin's finches. They spent more than 30 years on the project. Their efforts paid off. They were able to observe evolution by natural selection actually taking place. While the Grants were on the Galápagos, a drought occurred. As a result, fewer seeds were available for finches to eat. Birds with smaller beaks could crack open and eat only the smaller seeds. Birds with bigger beaks could crack and eat seeds of all sizes. As a result, many of the small-beaked birds died in the drought. Birds with bigger beaks survived and reproduced (See figure). Within 2 years, the average beak size in the finch population increased. Evolution by natural selection had occurred.



Evolution of Beak Size in Galápagos Finches. The top graph shows the beak sizes of the entire finch population studied by the Grants in 1976. The bottom graph shows the beak sizes of the survivors in 1978. In just 2 years, beak size increased.

Summary

- Fossils provide a window into the past. They are evidence for evolution. Scientists who find and study fossils are called paleontologists.
- Scientists compare the anatomy, embryos, and DNA of living things to understand how they evolved. Evidence for evolution is provided by homologous structures. These are structures shared by related organisms that were inherited from a common ancestor. Other evidence is provided by analogous structures. These are structures that unrelated organisms share because they evolved to do the same job.
- Biogeography is the study of how and why plants and animals live where they do. It also provides evidence for evolution. On island chains, such as the Galápagos, one species may evolve into many new species to fill available niches. This is called adaptive radiation.

Online Interactives/Simulations

INTERACTIVE: Play the following game to see how genetic variation, overproduction of offspring, and struggle for existence leads to evolution through the process of natural selection. Will your species survive?

- http://go.uen.org/b2q

Think like a Paleontologist

1. How do paleontologists learn about evolution?
2. Describe what fossils reveal about the evolution of the horse.
3. What are vestigial structures? Give an example.
4. Describe an example of island biogeography that provides evidence of evolution.
5. Humans and apes have five fingers they can use to grasp objects. Do you think these are analogous or homologous structures? Explain.
6. Compare and contrast homologous and analogous structures. What do they reveal about evolution?

Points to Consider

- The Grants saw evolution occurring from one generation to the next in a population of finches. What factors caused the short-term evolution the Grants witnessed? How did the Grants know that evolution had occurred? What other factors do you think might cause evolution to occur so quickly within a population?

5.2 How Does Evolution Happen

Objectives

Relate genetic variability to a species' potential for adaptation to a changing environment.

Relate reproductive isolation to speciation.

- Identify the role of mutation and recombination in evolution.

Introduction

Darwin knew that heritable variations are needed for evolution to occur. However, he knew nothing about Mendel's laws of genetics. Mendel's laws were rediscovered in the early 1900s. Only then could scientists fully understand the process of evolution.

The Scale of Evolution: How fast does Evolution happen?

We now know that variations of traits are heritable. These variations are determined by different alleles. We also know that evolution is due to a change in alleles over time. How long a time? That depends on the scale of evolution.

Microevolution occurs over a relatively short period of time within a population or species. The Grants observed this level of evolution in Darwin's finches.

Macroevolution occurs over geologic time above the level of the species. The fossil record reflects this level of evolution. It results from microevolution taking place over many generations.

Genes in Populations

Individuals do not evolve. Their genes do not change over time. The unit of evolution is the population. A population consists of organisms of the same species that live in the same area. In terms of evolution, the population is assumed to be a relatively closed group. This means that most mating takes place within the population. The science that focuses on evolution within populations is population genetics. It is a combination of evolutionary theory and Mendelian genetics.

Gene Pool

The genetic makeup of an individual is the individual's genotype. A population consists of many genotypes. Altogether, they make up the population's gene pool. The gene pool consists of all the genes of all the members of the population. For each gene, the gene pool includes all the different alleles for the gene that exist in the population. For a given gene, the population is characterized by the frequency of the different alleles in the gene pool.

Allele Frequencies

Allele frequency is how often an allele occurs in a gene pool relative to the other alleles for that gene. Look at the example in the Table below. The population in the table has 100 members. In a sexually reproducing species, each member of the population has two copies of each gene. Therefore, the total number of copies of each gene in the gene pool is 200. The gene in the example exists in the gene pool in two forms, alleles A and a. Knowing the genotypes of each population member, we can count the number of alleles of each type in the gene pool. Evolution occurs in a population when allele frequencies in the entire gene pool change over time.

Forces of Evolution

We can infer factors that cause allele frequencies to change. These factors are the forces of evolution. There are four such forces: mutation, gene flow, genetic drift, and natural selection.

Mutation

Mutation creates new genetic variation in a gene pool. It is how all new alleles first arise. In sexually reproducing species, the mutations that matter for evolution are those that occur in gametes. Only these mutations can be passed to offspring. For any given gene, the chance of a mutation occurring in a given gamete is very low. Thus, mutations alone do not have much effect on allele frequencies. However, mutations provide the genetic variation needed for other forces of evolution to act.

Gene Flow

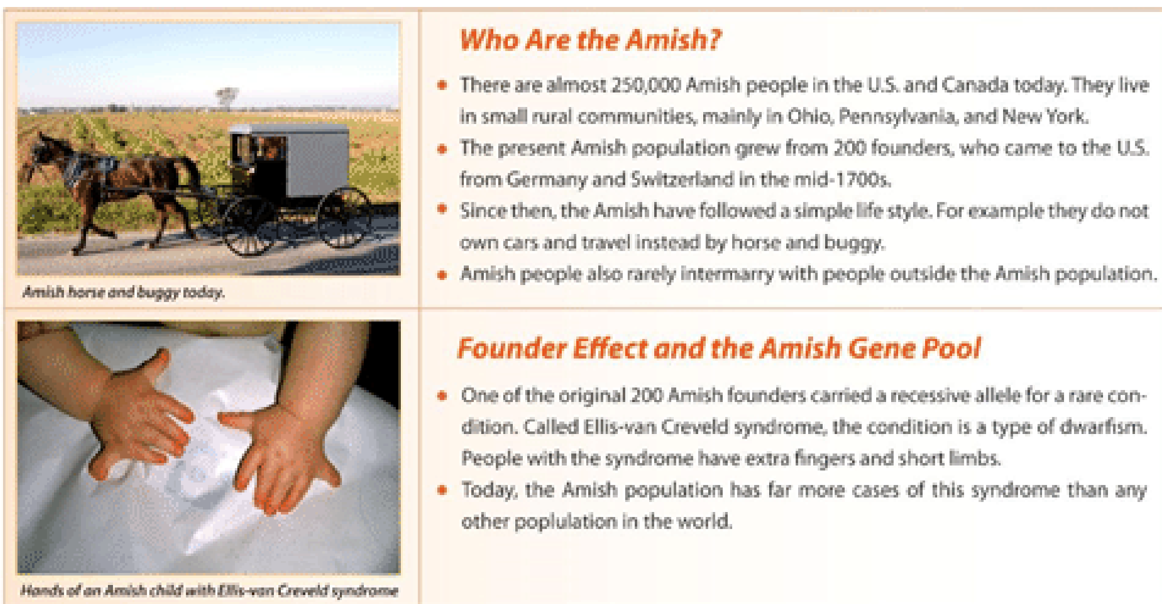
Gene flow occurs when individuals move into or out of a population. If the rate of migration is high, this can have a significant effect on allele frequencies. Both the population they leave and the population they enter may change.

During the Vietnam War in the 1960s and 1970s, many American servicemen had children with Vietnamese women. Most of the servicemen returned to the United States after the war. However, they left copies of their genes behind in their offspring. In this way, they changed the allele frequencies in the Vietnamese gene pool. Was the gene pool of the American population also affected? Why or why not?

Genetic Drift

Genetic drift is a random change in allele frequencies that occurs in a small population. When a small number of parents produce just a few offspring, allele frequencies in the offspring may differ, by chance, from allele frequencies in the parents. This is like tossing a coin. If you toss a coin just a few times, you may, by chance, get more or less than the expected 50 percent heads or tails. In a small population, you may also, by chance, get different allele frequencies than expected in the next generation. In this way, allele frequencies may drift over time. There are two special conditions under which genetic drift occurs. They are called bottleneck effect and founder effect.

- Bottleneck effect occurs when a population suddenly gets much smaller. This might happen because of a natural disaster such as a forest fire. By chance, allele frequencies of the survivors may be different from those of the original population.
- Founder effect occurs when a few individuals start, or found, a new population. By chance, allele frequencies of the founders may be different from allele frequencies of the population they left. An example is described in the Figure below.



Founder Effect in the Amish Population. The Amish population in the U.S. and Canada had a small number of founders. How has this affected the Amish gene pool?

Natural Selection

Natural selection occurs when there are differences in fitness among members of a population. As a result, some individuals pass more genes to the next generation. This causes allele frequencies to change. The example of sickle-cell anemia is described in the Figure below and Table below. It shows how natural selection can keep a harmful allele in a gene pool.

You can also watch a video about natural selection and sickle-cell anemia at this link:

- http://go.uen.org/b2r

Sickle Cell and Natural Selection.

Genotype	Phenotype	Fitness
AA	100% normal hemoglobin	Somewhat reduced fitness because of no resistance to malaria
AS	Enough normal hemoglobin to prevent sickle-cell anemia	Highest fitness because of resistance to malaria
SS	100% abnormal hemoglobin, causing sickle-cell anemia	Greatly reduced fitness because of sickle-cell anemia

Here's how natural selection can keep a harmful allele in a gene pool:

- The allele (S) for sickle-cell anemia is a harmful autosomal recessive. It is caused by a mutation in the normal allele (A) for hemoglobin (a protein on red blood cells).
- Malaria is a deadly tropical disease. It is common in many African populations.
- Heterozygotes (AS) with the sickle-cell allele are resistant to malaria. Therefore, they are more likely to survive and reproduce. This keeps the S allele in the gene pool.

The sickle-cell example shows that fitness depends on phenotypes. It also shows that fitness may depend on the environment. What do you think might happen if malaria was eliminated in an African population with a relatively high frequency of the S allele? How might the fitness of the different genotypes change? How might this affect the frequency of the S allele? Sickle-cell trait is controlled by a single gene. Natural selection for polygenic traits is more complex, unless you just look at phenotypes. Three ways that natural selection can affect phenotypes are shown in the Figure below.

For a review of natural selection and genetic drift, and how they relate to evolution, see:

- http://go.uen.org/b2s

Mutation, natural selection, genetic drift and gene flow are discussed at:

- http://go.uen.org/b2t (8:45)

Summary

- Microevolution occurs over a short period of time in a population or species. Macroevolution occurs over geologic time above the level of the species.
- The population is the unit of evolution. A population's gene pool consists of all the genes of all the members of the population. For a given gene, the population is characterized by the frequency of different alleles in the gene pool.
- There are four forces of evolution: mutation, gene flow, genetic drift, and natural selection. Natural selection for a polygenic trait changes the distribution of phenotypes.

Think like an Evolutionary Biologist

1. Why are populations, rather than individuals, the units of evolution?
2. What is a gene pool?
3. Identify the four forces of evolution.
4. Why is mutation needed for evolution to occur, even though it usually has little effect on allele frequencies?
5. Compare and contrast microevolution and macroevolution. How are the two related?

Points to Consider

Disruptive selection for a polygenic trait results in two overlapping phenotypes. Theoretically, disruptive selection could lead to two new species forming.

- How might this happen?
- Can you describe how it could occur?
- How else might one species diverge into two?

Speciation: What Causes Speciation?

Objectives

- Relate genetic variability to a species' potential for adaptation to a changing environment.
- Relate reproductive isolation to speciation.
- Identify the role of mutation and recombination in evolution.

Introduction

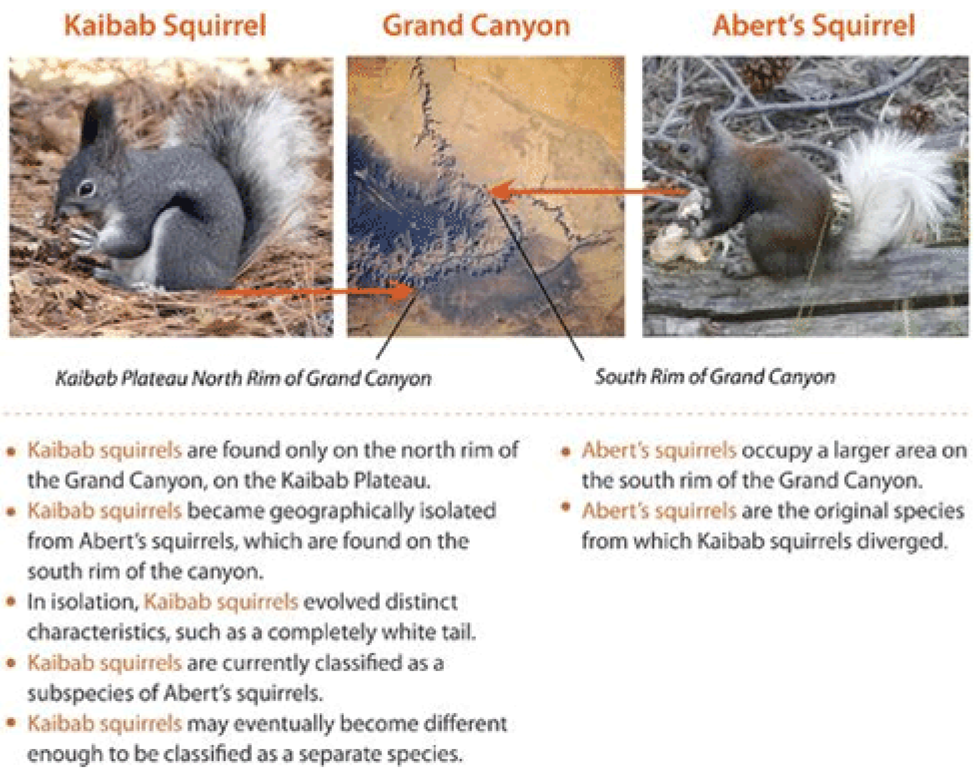
Macroevolution is evolution over geologic time above the level of the species. One of the main topics in macroevolution is how new species arise. The process by which a new species evolves is called speciation. How does speciation occur? How does one species evolve into two or more new species?

Origin of Species

To understand how a new species forms, it's important to review what a species is. A species is a group of organisms that can breed and produce fertile offspring together in nature. For a new species to arise, some members of a species must become reproductively isolated from the rest of the species. This means they can no longer interbreed with other members of the species. How does this happen? Usually they become geographically isolated first.

Allopatric Speciation

Assume that some members of a species become geographically separated from the rest of the species. If they remain separated long enough, they may evolve genetic differences. If the differences prevent them from interbreeding with members of the original species, they have evolved into a new species. Speciation that occurs in this way is called allopatric speciation. (See figure).



Allopatric Speciation in the Kaibab Squirrel. The Kaibab squirrel is in the process of becoming a new species.

Watch the following video on speciation:

- http://go.uen.org/b2u

Sympatric Speciation

Less often, a new species arises without geographic separation. This is called sympatric speciation. The following example shows one way this can occur.

- Hawthorn flies lay eggs in hawthorn trees (See figure). The eggs hatch into larvae that feed on hawthorn fruits. Both the flies and trees are native to the U.S.
- Apple trees were introduced to the U.S. and often grow near hawthorn trees. Some hawthorn flies started to lay eggs in nearby apple trees. When the eggs hatched, the larvae fed on apples.
- Over time, the two fly populations — those that fed on hawthorn trees and those that preferred apple trees — evolved reproductive isolation. Now they are reproductively isolated because they breed at different times. Their breeding season matches the season when the apple or hawthorn fruits mature.
- Because they rarely interbreed, the two populations of flies are evolving other genetic differences. They appear to be in the process of becoming separate species.

Sympatric Speciation in Hawthorn Flies. Hawthorn flies are diverging from one species into two. As this example shows, behaviors as well as physical traits may evolve and lead to speciation.

Coevolution

Evolution occurs in response to a change in the environment. Environmental change often involves other species of organisms. In fact, species in symbiotic relationships tend to evolve together. This is called coevolution. As one species changes, the other species must also change in order to adapt.

Coevolution occurs in flowering plants and the species that pollinate them. The flower and bird in the Figure below are a good example. They have evolved matching structures.

Results of Coevolution in a Flower and Its Pollinator.

The very long mouth part of this hummingbird has coevolved with the tubular flower it pollinates. Only this species of bird can reach the nectar deep in the flower. What might happen to the flower if the bird species went extinct?

Timing of Macroevolution

Is evolution slow and steady? Or does it occur in fits and starts? It may depend on what else is going on, such as changes in climate and geologic conditions.

- When geologic and climatic conditions are stable, evolution may occur gradually. This is how Darwin thought evolution occurred. This model of the timing of evolution is called gradualism.
- When geologic and climatic conditions are changing, evolution may occur more quickly. Thus, long periods of little change may be interrupted by bursts of rapid change. This model of the timing of evolution is called punctuated equilibrium. It is better supported by the fossil record than is gradualism.

Summary

- New species arise in the process of speciation. Allopatric speciation occurs when some members of a species become geographically separated. They then evolve genetic differences. If the differences prevent them from interbreeding with the original species, a new species has evolved. Sympatric speciation occurs without geographic separation.
- Coevolution occurs when species evolve together. This often happens in species that have symbiotic relationships. Examples include flowering plants and their pollinators.
- Darwin thought that evolution occurs gradually. This model of evolution is called gradualism. The fossil record better supports the model of punctuated equilibrium. In this model, long periods of little change are interrupted by bursts of rapid change.

5.3 Classification of Living Things

How do we classify living things?

Objectives

- Classify organisms using a classification tool such as a key or field guide.
- Generalize criteria used for classification of organisms (e.g., dichotomy, specific).
- Explain how evolutionary relationships are related to classification systems.
- Justify the ongoing changes to classification schemes used in biology.

Classification of Life

When you see an organism that you have never seen before, you probably put it into a group without even thinking. If it is green and leafy, you probably call it a plant. If it is long and slithers, you probably call it as a snake. How do you make these decisions? You look at the physical features of the organism and think about what it has in common with other organisms.

Scientists do the same thing when they classify– (to put into categories) living things. Scientists classify organisms not only by their physical features, but also by how closely related they are. Lions and tigers look like each other more than they look like bears, but are lions and tigers related? Evolutionarily speaking, yes. Lions and tigers both evolved from a common ancestor. So it turns out that the two cats are actually more closely related to each other than to bears. How an organism looks and how it is related to other organisms determines how it is classified.

Linnaean System of Classification: Who was Carl Linnaeus?

People have been concerned with classifying organisms for thousands of years. Over 2,000 years ago, the Greek philosopher Aristotle developed a classification system that divided living things into several groups that we still use today, including mammals, insects, and reptiles.

Carl Linnaeus (1707-1778) built on Aristotle’s work to create his own classification system. He invented the way we name organisms today, with each organism having a two word name. Linnaeus is considered the inventor of modern taxonomy (the science of naming and grouping organisms).

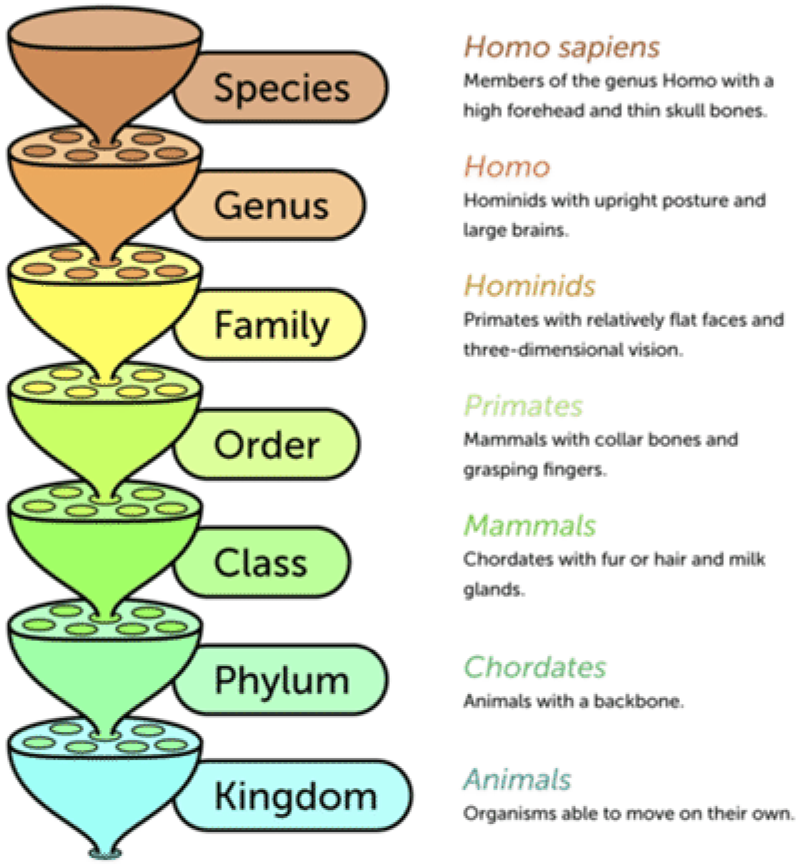
In the 18th century, Carl Linnaeus invented the two-name system of naming organisms using genus and species and introduced the most complete classification system then known.

Linnaeus developed binomial nomenclature. In this system, each organism receives a two-part name in which the first word is the genus and the second word refers to one species in that genus. For example, a coyote's species name is *Canis latrans. Latrans* is the species and *Canis* is the genus, a larger group that includes dogs, wolves, and other dog-like animals. Here is another example: the red maple, *Acer rubra*, and the sugar maple, *Acer saccharum,* are both in the same genus and they look similar (See figure). Notice that the genus is capitalized and the species is not, and that the whole scientific name is in italics. The names may seem strange, but the names are written in a language called Latin.

These leaves are from one of two different species of trees in the Acer, or maple, genus. The green leaf (far left) is from the sugar maple, and the red leaves (center) are from the red maple. One of the characteristics of the maple genus is winged seeds (far right).

Modern Classification

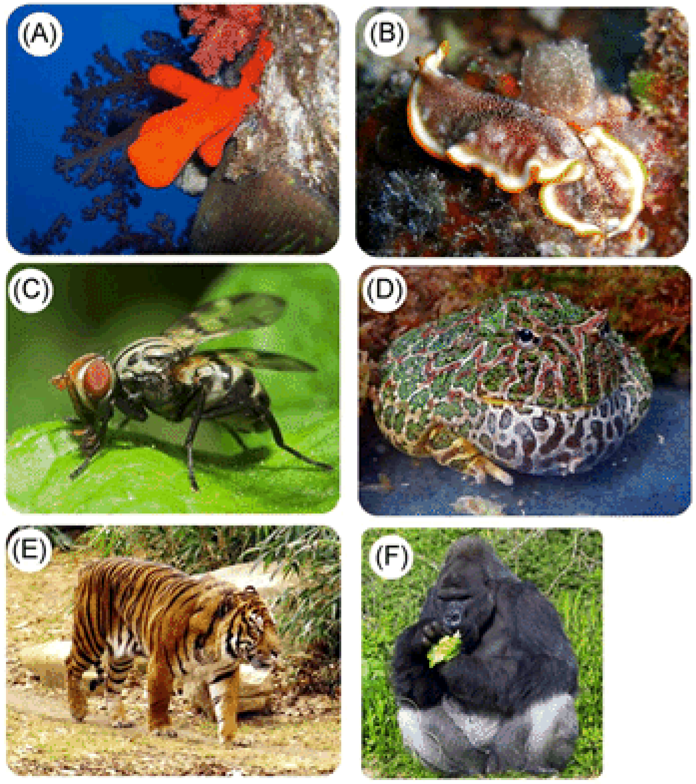
Modern taxonomists have reordered many groups of organisms since Linnaeus. The main categories that biologists use are listed here from the most specific to the least specific category. All organisms can be classified into one of three domains which are the least specific grouping. The three domains are Bacteria, Archaea, and Eukarya. The Kingdom is the next category after the Domain. All life is divided among six kingdoms: Kingdom Bacteria, Kingdom Archaea, Kingdom Protista, Kingdom Plantae, Kingdom Fungi, and Kingdom Animalia.



This diagram illustrates the classification categories for organisms, with the broadest category (kingdom) at the bottom, and the most specific category (species) at the top. We are Homo sapiens. Homo is the genus of great apes that includes modern humans and closely related species, and sapiens is the only living species of the genus.

Classifying Animals

There is great variation among species which is a group of individuals that are genetically related and can breed to produce fertile young that make up the animal kingdom. Despite the variation, there are a number of traits that are shared by all animals. The fact that all animals have certain traits in common shows that they share a common ancestor. How did such a diverse group of organisms evolve? What traits do all animals share? Read on to find out.



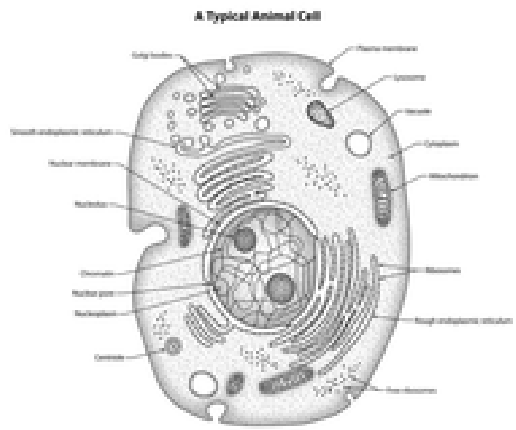
Diversity of Animals. These photos give just an inkling of the diversity of organisms that belong to the animal kingdom. (A) Sponge (B) Flatworm (C) Flying Insect (D) Frog (E) Tiger (F) Gorilla.

Characteristics of Animals

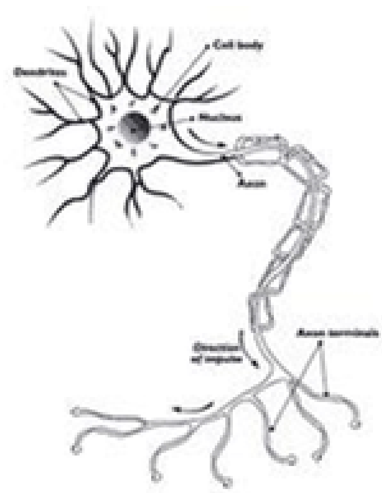
Living things are classified into three domains. Animals are in the domain Eukarya. Animals are a kingdom –broad grouping of similar organisms of multicellular eukaryotes that cannot make their own food. Instead, they get nutrients by eating other living things. Therefore, animals are heterotrophs that get their energy by eating other organisms.

Animal Cells

Like the cells of all eukaryotes animal cells have a nucleus and other membrane-bound organelles. Unlike the cells of plants (multicellular autotrophs) and fungi (single and multicellular heterotrophic decomposers), animal cells lack a cell wall. This gives animal cells flexibility. It lets them take on different shapes so they can become specialized to do particular jobs. The human nerve cell shown below is a good example. Its shape suits it for its function of transmitting nerve impulses over long distances. A nerve cell would be unable to take this shape if it were surrounded by a rigid cell wall.



Animal Cell. The shape of an animal cell is not constrained by a rigid cell wall. A bacterial cell is shown above for comparison.



Human Nerve Cell. A human nerve cell is specialized to transmit nerve impulses.

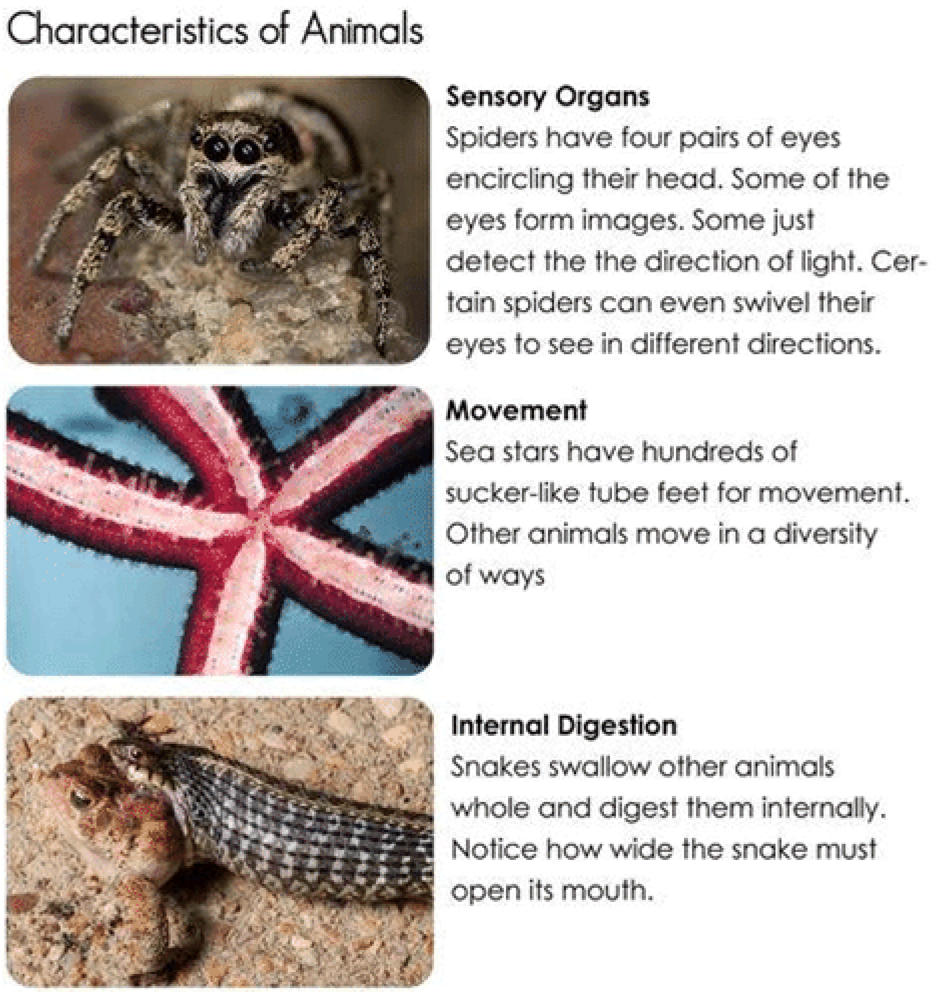
Animal Structure and Function

Animals have more than just specialized cells. Most animals also have tissues and organs. In many animals, organs form organ systems, such as a nervous system. Higher levels of organization allow animals to perform many complex functions. What can animals do that most other living things cannot? Here are some examples.

Animals can detect environmental stimuli, such as light, sound, and touch. Stimuli are detected by sensory nerve cells. The information is transmitted and processed by the nervous system. The nervous system, in turn, may direct the body to respond.

All animals can move, at least during some stage of their life cycle. Muscles and nerves work together to allow movement. Being able to move allows animals to actively search for food and mates. It also helps them escape from predators.

Virtually all animals have internal digestion of food. Animals consume other organisms and may use special tissues and organs to digest them. Many other organisms absorb nutrients directly from the environment.



Characteristics of Animals. Most animals share these characteristics: sensory organs, movement, and internal digestion.

Think like an Evolutionary Biologist

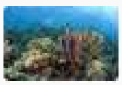
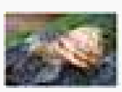
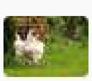
1. Identify traits that characterize all animals.
2. State one way that animal cells differ from the cells of plants and fungi. What is the significance of this difference?
3. Describe a general animal life cycle.
4. State how the phylum Chordata differs from other animal phyla.
5. Compare and contrast invertebrates and vertebrates.
6.

Animals: How do we classify animals?

All animals share basic traits. But animals also show a lot of diversity. They range from simple sponges to complex humans.

Major Animal Phyla

Members of the animal kingdom are divided into more than 30 phyla. Table below lists the 9 phyla with the greatest number of species. Each of the animal phyla listed in the table have at least 10,000 species.

	Phylum	Animals it Includes
	Porifera	Sponges
	Cnidaria	jellyfish, corals
	Platyhelminthes	flatworms, tapeworms, flukes
	Nematoda	Roundworms
	Mollusca	snails, clams, squids
	Annelida	earthworms, leeches, marine worms
	Arthropoda	insects, spiders, crustaceans, centipedes
	Echinodermata	sea stars, sea urchins, sand dollars, sea cucumbers
	Chordata	tunicates, lancelets, fish, amphibians, reptiles, birds, mammals

Invertebrate vs. Vertebrate

The first eight phyla listed in the Table previous include only invertebrates. The last phylum in the table, the Chordata, also includes many invertebrate species. Tunicates and lancelets are both invertebrates. Altogether, invertebrates make up at least 95 percent of all animal species. The remaining animals are vertebrates. All vertebrates belong to the phylum Chordata. They include fish, amphibians, reptiles, birds, and mammals.

For a video that helps explain how we classify living things, visit:

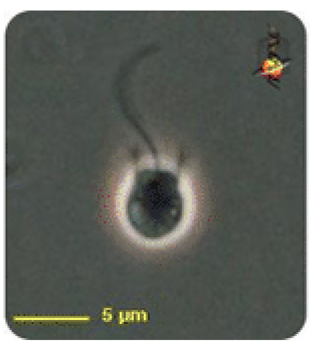
- http://go.uen.org/b2v

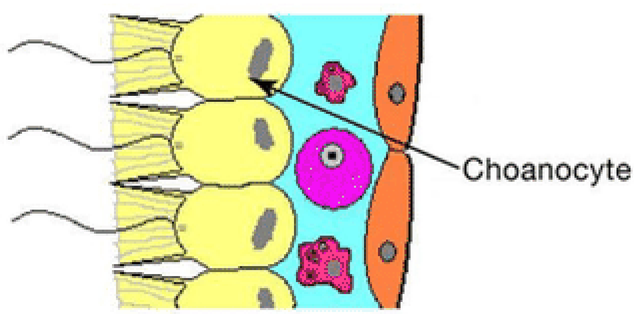
Major Trends in Animal Evolution

The oldest animal fossils are about 630 million years old. By 500 million years ago, most modern phyla of animals had evolved.

Animal Origins

Who were the ancestors of the earliest animals? They may have been marine protists that lived in colonies. Scientists think that cells of some protist colonies became specialized for different jobs. After a while, the specialized cells came to need each other for survival. Thus, the first multicellular animal evolved. Look at the cells in the figure below. One type of sponge cell, the choanocyte, looks a lot like the protist cell. How does this support the hypothesis that animals evolved from protists?





Choanoflagellate Protist and Choanocyte Cells in Sponges. Sponge choanocytes look a lot like choanoflagellate protists.

Evolution of Invertebrates

Many important animal adaptations evolved in invertebrates. Without these adaptations, vertebrates would not have been able to evolve.

They include:

- Tissues, organs, and organ systems.
- A symmetrical body.

- A brain and sensory organs.
- A fluid-filled body cavity.
- A complete digestive system.
- A body divided into segments.

You can read about all of these adaptations in the next lesson.

Moving from Water to Land

When you think of the first animals to colonize the land, you may think of amphibians. It's true that ancestors of amphibians were the first vertebrates to move to land. However, the very first animals to go ashore were invertebrates, most likely arthropods.

The move to land required new adaptations. For example, animals needed a way to keep their body from drying out. They also needed a way to support their body on dry land without the buoyancy of water. One way early arthropods solved these problems was by evolving an exoskeleton that supports the body and helps retain water.

The video Walking with Monsters is a depiction of the evolution of life from water onto land:

- http://go.uen.org/b2w (4:43)

Evolution of Chordates

Another major step in animal evolution was the evolution of a notochord which is a rigid rod that runs the length of the body. It supports the body and gives it shape (See figure). It also provides a place for muscles to anchor, and counterbalances them when they contract. Animals with a notochord are called chordates. They also have a hollow nerve cord that runs along the top of the body. Gill slits and a tail are two other chordate features. Many modern chordates have some of these structures only as embryos.

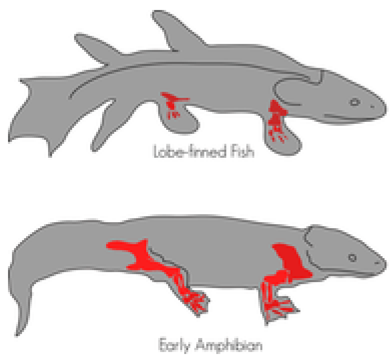
Primitive Chordate: Tunicate. This tunicate is a primitive, deep-sea chordate. It is using its notochord to support its head, while it waits to snatch up prey in its big mouth.

Evolution of Vertebrates

Vertebrates evolved from primitive chordates. This occurred about 550 million years ago. The earliest vertebrates may have been jawless fish, like the hagfish (See figure). Vertebrates evolved a backbone to replace the notochord after the embryo stage. They also evolved a cranium, or bony skull, to enclose and protect the brain.

Primitive Vertebrate: Hagfish. Hagfish are very simple vertebrates.

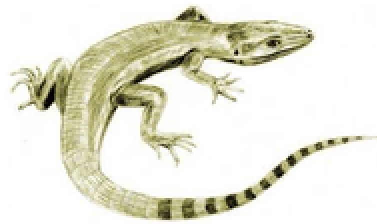
As early vertebrates evolved, they became more complex. Around 365 million years ago, they finally made the transition from water to land. The first vertebrates to live on land were amphibians. They evolved from lobe-finned fish. (See figure)



From Lobe-Finned Fish to Early Amphibian. Lobe-finned fish evolved into the earliest amphibians. A lobe-finned fish could breathe air for brief periods of time. It could also use its fins to walk on land for short distances. What similarities do you see between the lobe-finned fish and the amphibian?

Evolution of Amniotes

Amphibians were the first animals to have true lungs and limbs for life on land. However, they still had to return to water to reproduce. That's because their eggs lacked a waterproof covering and would dry out on land. The first fully terrestrial vertebrates were amniotes. Amniotes are animals that produce eggs with internal membranes. The membranes let gases but not water pass through. Therefore, in an amniotic egg, an embryo can breathe without drying out. Amniotic eggs were the first eggs that could be laid on land. The earliest amniotes evolved about 350 million years ago.



Early Amniote. The earliest amniotes probably looked something like this. They were reptile-like, but not actually reptiles. Reptiles evolved somewhat later.

Think like an Evolutionary Biologist

1. List three traits that evolved in invertebrate animals.

2. Assume that a new species of animal has been discovered. It is an egg-laying animal that lives and reproduces on land. Explain what you know about its eggs without ever seeing them.

3. Vertebrates are the animals with which we are most familiar. But there are far more invertebrates than vertebrates on the planet. The next lesson provides an overview of invertebrate animals.

4. Invertebrates are sometimes referred to as “lower” animals. This is because they evolved earlier and are simpler than vertebrates. Do you think invertebrates are also less adapted to their environments than vertebrates? Why or why not?

Mass Extinction: How has classification changed?

The Cretaceous Period ended with another mass extinction. This occurred about 65 million years ago. All of the dinosaurs went extinct at that time. Did the extinction of the dinosaurs allow mammals to take over?

Traditional View

Scientists have long assumed that the extinction of the dinosaurs opened up many niches for mammals to exploit. Presumably, this led to an explosion of new species of mammals early in Cenozoic Era. Few mammalian fossils from the early Cenozoic have been found to support this theory. Even so, this way of thinking was still widely accepted until recently.

View from the Mammalian Supertree

In 2007, an international team of scientists compared the DNA of almost all known species of living mammals. They used the data to create a supertree of mammalian evolution. The supertree shows that placental mammals started to diversify as early as 95 million years ago.

What explains the diversification of mammals long before the dinosaurs went extinct? What else was happening at that time? One change was a drop in Earth's temperature. This may have favored endothermic mammals over ectothermic dinosaurs. Flowering plants were also spreading at that time. They may have provided new and plentiful foods for small mammals or their insect prey.

The supertree also shows that another major diversification of mammals occurred about 50 million years ago. Again, worldwide climate change may have been one reason. This time Earth's temperature rose. The warmer temperature led to a greater diversity of plants. This would have meant more food for mammals or their prey.

Classification of Placental Mammals

Traditional classifications of mammals are based on similarities in structure and function. Increasingly, mammals are being classified on the basis of molecular similarities.

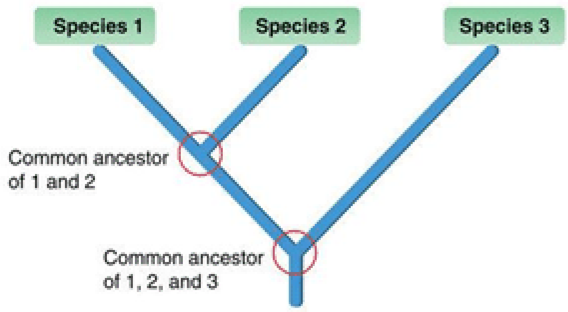
Traditional Classification

The most widely accepted traditional classification of mammals divides living placental mammals into 17 orders. This hierarchy (system of organization) is shown in the table below. This classification of mammals was widely accepted for more than 50 years. Placental mammals are still commonly placed in these orders. However, this classification is not very useful for studies of mammalian evolution. That's because it groups together some mammals that do not seem to be closely related by descent from a recent common ancestor.

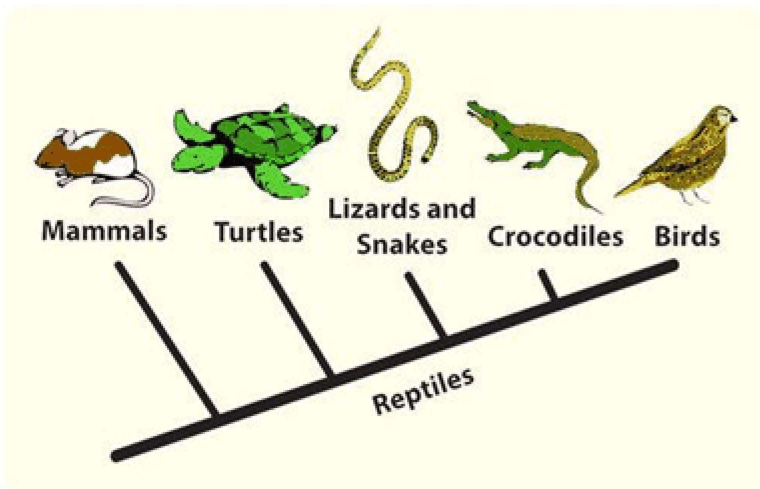
Order	Example	Sample Trait
Insectivora	Mole	small sharp teeth
Edentata	Anteater	few or no teeth
Pholidota	Pangolin	large plate-like scales
Chiroptera	Bat	digits support membranous wings
Carnivora	Coyote	long pointed canine teeth
Rodentia	Mouse	incisor teeth grow continuously
Lagomorpha	Rabbit	chisel-like incisor teeth
Perissodactyla	Horse	odd-toed hooves
Artiodactyla	Deer	even-toed hooves
Cetacea	Whale	paddle-like forelimbs
Primates	Monkey	five digits on hands and feet
Proboscidea	Elephant	tusks
Hyracoidea	Hyrax	rubbery pads on feet
Dermoptera	colugo	membrane of skin between legs for gliding
Pinnipedia	seal	feet with fins
Sirenia	manatee	paddle-like tail
Tubulidentata	aardvark	teeth without enamel

Phylogenetic Classification

The mammalian supertree classifies placental mammals phylogenetically. It groups together mammals that are closely related because they share a recent common ancestor. These groups are not necessarily the same as the traditional groups based on structure and function.



This phylogenetic tree shows how three hypothetical species are related to each other through common ancestors. Do you see why Species 1 and 2 are more closely related to each other than either is to Species 3?



Dichotomous Key

A dichotomous key is a tool that taxonomists often use to classify organisms correctly. It is a form of hierarchical grouping that involves making decisions in a series of steps, from general differences to very specific differences. It is called a dichotomous key because there are always two choices. There is a very specific way to set up a dichotomous key. For instance, one must always move from the general to the specific, and one must always ensure that the two choices in the decision tree are mutually exclusive and jointly exhaustive. Mutually exclusive means that there cannot be overlap between the two options, as this would result in wanting to place an organism in two groups. Jointly exhaustive means that your two options must cover all possibilities, otherwise you won't be able to place an organism in either of the groups.

	Characteristic	Instruction
1a	Arthropod has eight legs.	go 2 (Arachnids)
1b	Arthropod does not have 8 legs.	go 4
2a	Arachnid has pedipalp with pincers.	SCORPION
2b	Arachnid does not have pedipalp with pincers.	Go 3
3a	Arachnid drinks blood.	TICK
3b	Arachnid does not drink blood.	SPIDER
4a	Arthropod has more than 16 legs.	Go 9 (Myriapoda)
4b	Arthropod does not have more than 16 legs.	Go 5
5a	Arthropod has 3 pairs of legs.	Go 6 (Insects)
5b	Arthropod does not 3 pairs of legs.	CRUSTACEAN
6a	Insect has hardened fore-wings.	COLEOPTERA
6b	Insect does not have hardened fore-wings.	Go 7
7a	Insects are social and/ or live in a hive.	HYMENOPTERA
7b	Insects are not social, do not live in a hive.	Go 8
8a	Insects does not have a sponge-like proboscis.	LEPIDOPTERA
8b	Insects have a sponge-like proboscis.	DIPTERA
9a	Myriapod with one pair of legs per segment.	CENTIPEDE
9b	Myriapod with two pairs of legs per segment.	MILLIPEDE

Summary

- Animals are multicellular eukaryotes that lack cell walls. All animals are heterotrophs. They have sensory organs, the ability to move, and internal digestion. They also have sexual reproduction.

- Vertebrates have a backbone, but invertebrates do not. Except for the chordates, all animal phyla consist only of invertebrates. Chordates include both vertebrates and invertebrates.
- The earliest animals evolved from colonial protists more than 600 million years ago. Many important animal adaptations evolved in invertebrates, including tissues and a brain. The first animals to live on land were invertebrates.
- Amphibians were the first vertebrates to live on land. Amniotes were the first animals that could reproduce on land.
- Amniotes called synapsids were the ancestors of mammals. Synapsids named pelycosaurs had some of the traits of mammals by 275 million years ago. Some of them evolved into therapsids, which became widespread during the Permian Period. The few therapsids that survived the Triassic takeover were small, arboreal insect eaters. They were also nocturnal. Being active at night may explain why they survived and evolved still more mammalian traits.
- Monotremes evolved about 150 million years ago. Like modern monotremes, they had a cloaca and laid eggs. Marsupials evolved about 130 million years ago. They were very small and ate insects and worms. Placental mammals evolved about 110 million years ago. They were also small and climbed trees. Placental mammals became the dominant land mammals. Most marsupials and monotremes died out except in Australia.
- Mammals used to be classified on the basis of similarities in structure and function into 17 different orders. Recently, DNA analyses have shown that the traditional orders include mammals that are not closely related. Phylogenetic classification, based on DNA data, groups placental mammals in four superorders. The superorders appear to have become distinct from each other 85–105 million years ago.

Think like an Evolutionary Biologist

1. Assume that a new species of placental mammal has been discovered. Scientists have examined it closely and studied its DNA. It has wings similar to a bat that it uses for gliding. Its DNA is most similar to the DNA of rodents such as mice. How would you classify the new mammal? Explain your answer.
2. Relate the extinction of dinosaurs to the diversification of modern mammals.
3. Compare and contrast traditional and phylogenetic classifications of placental mammals. Explain which type of classification is more useful for understanding how mammals evolved.

Points to Consider

- Some mammalian traits, such as different types of teeth, evolved in ancestors of mammals. Other traits, such as placental reproduction, evolved after the first mammals appeared. Mammals also evolved many behavioral traits.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